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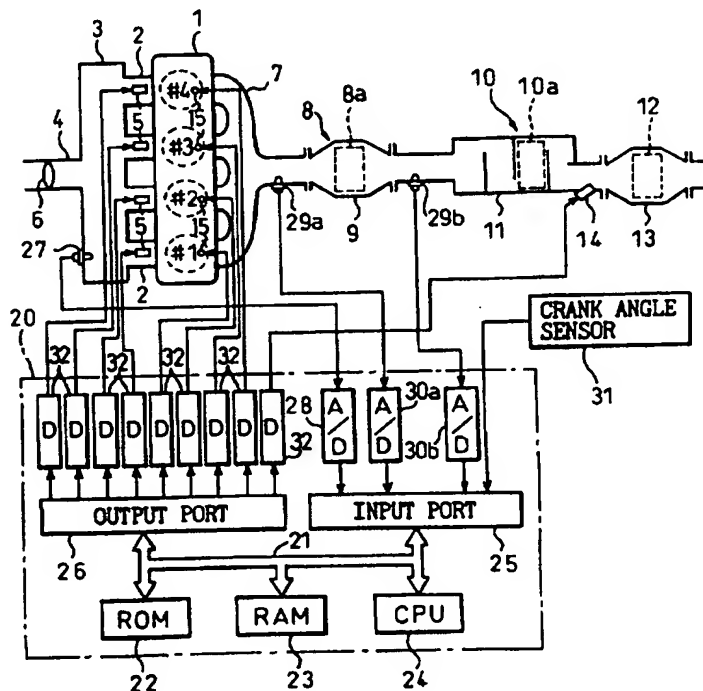
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(54) Title: METHOD AND DEVICE FOR PURIFYING EXHAUST GAS OF ENGINE

## (57) Abstract

An exhaust manifold (7) of an engine (1) is connected to a three way (TW) catalyst (8a), and the TW catalyst (8a) is connected to an NH<sub>3</sub> adsorbing and oxidizing (NH<sub>3</sub>-AO) catalyst (10a). The engine (1) performs the lean and the rich engine operations alternately and repeatedly. When the engine (1) performs the rich operation and thereby the exhaust gas air-fuel ratio of the exhaust gas flowing into the TW catalyst (8a) is made rich, NO<sub>x</sub> in the inflowing exhaust gas is converted to NH<sub>3</sub> in the TW catalyst (8a). The NH<sub>3</sub> is then adsorbed in the NH<sub>3</sub>-AO catalyst (10a). Next, when the engine (1) performs the lean operation and thereby the exhaust gas air-fuel ratio of the exhaust gas flowing into the TW catalyst (8a) is made lean, NO<sub>x</sub> in the exhausted gas passes through the TW catalyst (8a), and flows into the NH<sub>3</sub>-AO catalyst (10a). At this time, NH<sub>3</sub> adsorbed in the catalyst (10a) is desorbed therefrom, and reduces the inflowing NO<sub>x</sub>.



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WO 97/17532

PCT/JP96/03205

- 1 -

# DESCRIPTION

## Method and Device for Purifying Exhaust Gas of Engine

5

### TECHNICAL FIELD

The present invention relates to a method and a device for purifying an exhaust gas of an engine.

### BACKGROUND ART

10 If an air-fuel ratio of an air-fuel mixture in a combustion chamber of an internal combustion engine is referred as an engine air-fuel ratio, an exhaust gas purifying device for an internal combustion engine with multi-cylinder has been known, in which a three-way catalyst is arranged in an exhaust passage, and the engine air-fuel ratio is controlled to be stoichiometric or rich with respect to the stoichiometric air-fuel ratio. If the engine air-fuel ratio is made lean with respect to the stoichiometric air-fuel ratio, the three way catalyst does not purify nitrogen oxides NO<sub>x</sub> in the exhaust gas sufficiently, and thus the NO<sub>x</sub> is emitted to the ambient air. Accordingly, the exhaust gas purifying device mentioned above makes the engine air-fuel ratio stoichiometric or rich, to thereby purify NO<sub>x</sub>, at the three-way catalyst, as much as possible.

20 On the other hand, a lower fuel consumption rate is desirable, and thus it is desirable to make the engine air-fuel ratio as lean as possible. However, if the engine air-fuel ratio is made lean, the above-mentioned exhaust gas purifying device cannot purify NO<sub>x</sub> sufficiently. To solve this problem, Japanese Unexamined Patent Publication No. 4-365920 discloses an exhaust gas purifying device for an internal combustion engine with multi-cylinders, the engine having first and second cylinder groups. The purifying device is provided with; an engine operation control device to continuously make

each cylinder operation of the first cylinder group a rich engine operation in which the engine air-fuel ratio is rich, and to continuously make each cylinder operation of the second cylinder group a lean engine operation in which the engine air-fuel ratio is lean; a first exhaust passage connected to each cylinder of the first cylinder group; a second exhaust passage connected to each cylinder of the second cylinder group and different from the first exhaust passage; an  $\text{NH}_3$  synthesizing catalyst arranged in the first exhaust passage for synthesizing ammonium  $\text{NH}_3$  from at least a part of  $\text{NO}_x$  in the inflowing exhaust gas; an interconnecting passage interconnecting the first exhaust passage downstream of the  $\text{NH}_3$  synthesizing catalyst and the second exhaust passage to each other; and an exhaust gas purifying catalyst arranged in the interconnecting passage to react  $\text{NO}_x$  and  $\text{NH}_3$  flowing therein to each other to thereby purify  $\text{NO}_x$  and  $\text{NH}_3$  simultaneously. In this exhaust gas purifying device, the fuel consumption rate is reduced by increasing the numbers of the cylinders of the second cylinder group in which the lean engine operation is performed, while purifying  $\text{NO}_x$  by synthesizing  $\text{NH}_3$  from  $\text{NO}_x$  exhausted from the first group and reacting the  $\text{NH}_3$  and  $\text{NO}_x$  from the second group.

However, this device requires two, separate exhaust passages, one for the first cylinder group, and the other for the second cylinder group. This complicates the structure of the device, and makes the size of the device larger.

#### DISCLOSURE OF THE INVENTION

An object of the present invention is to provide a method and a device for purifying an exhaust gas of an engine which can purify the exhaust gas sufficiently with a simple structure.

According to one aspect of the present invention, there is provided a method for purifying an exhaust gas



of an engine, comprising, in turn: forming an exhaust gas portion of which an exhaust gas air-fuel ratio is lean, and an exhaust gas portion of which the exhaust gas air-fuel ratio is rich, from the exhaust gas of the engine, alternately and repeatedly; and contacting the exhaust gas portions an  $\text{NH}_3$  synthesizing catalyst and an exhaust gas purifying catalyst comprised of at least one selected from the group consisted of an  $\text{NH}_3$  adsorbing and oxidizing ( $\text{NH}_3$ -AO) catalyst and a  $\text{NO}_x$  occluding and reducing ( $\text{NO}_x$ -OR) catalyst, in turn, the  $\text{NH}_3$  synthesizing catalyst synthesizing  $\text{NH}_3$  from at least a part of  $\text{NO}_x$  in the inflowing exhaust gas when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich, and passing  $\text{NO}_x$  in the inflowing exhaust gas therethrough when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, the  $\text{NH}_3$ -AO catalyst adsorbing  $\text{NH}_3$  in the inflowing exhaust gas therein, and desorbing the adsorbed  $\text{NH}_3$  therefrom and oxidizing the  $\text{NH}_3$  when an  $\text{NH}_3$  concentration in the inflowing exhaust gas becomes lower, and the  $\text{NO}_x$ -OR catalyst occluding  $\text{NO}_x$  in the inflowing exhaust gas therein when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, and releasing the occluded  $\text{NO}_x$  therefrom and reducing the  $\text{NO}_x$  when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich.

According to another aspect of the present invention, there is provided a device for purifying an exhaust gas of an engine having an exhaust passage, comprising: exhaust gas portion forming means arranged in the engine or the exhaust passage for forming an exhaust gas portion of which an exhaust gas air-fuel ratio is lean, and an exhaust gas portion of which the exhaust gas air-fuel ratio is rich, from the exhaust gas of the engine, alternately and repeatedly; an  $\text{NH}_3$  synthesizing catalyst arranged in the exhaust passage

downstream of the exhaust gas portion forming means, the  
NH<sub>3</sub> synthesizing catalyst synthesizing NH<sub>3</sub> from at least  
a part of NO<sub>x</sub> in the inflowing exhaust gas when the  
exhaust gas air-fuel ratio of the inflowing exhaust gas  
5 is rich, and passing NO<sub>x</sub> in the inflowing exhaust gas  
therethrough when the exhaust gas air-fuel ratio of the  
inflowing exhaust gas is lean; and an exhaust gas  
purifying catalyst arranged in the exhaust passage  
downstream of the NH<sub>3</sub> synthesizing catalyst, the exhaust  
10 gas purifying catalyst comprising at least one selected  
from the group consisting of an NH<sub>3</sub> adsorbing and  
oxidizing (NH<sub>3</sub>-AO) catalyst and a NO<sub>x</sub> occluding and  
reducing (NO<sub>x</sub>-OR) catalyst, the NH<sub>3</sub>-AO catalyst adsorbing  
NH<sub>3</sub> in the inflowing exhaust gas therein, and desorbing  
15 the adsorbed NH<sub>3</sub> therefrom and oxidizing the NH<sub>3</sub> when the  
NH<sub>3</sub> concentration in the inflowing exhaust gas becomes  
lower, and the NO<sub>x</sub>-OR catalyst occluding NO<sub>x</sub> in the  
inflowing exhaust gas therein when the exhaust gas  
air-fuel ratio of the inflowing exhaust gas is lean, and  
20 releasing the occluded NO<sub>x</sub> therefrom and reducing the NO<sub>x</sub>  
when the exhaust gas air-fuel ratio of the inflowing  
exhaust gas is rich.

The present invention may be more fully understood  
from the description of preferred embodiments of the  
25 invention set forth below, together with the accompanying  
drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a general view of an internal combustion  
engine; Fig. 2A illustrates a characteristic of a  
30 three-way catalyst; Fig. 2B illustrates a variation of a  
NO<sub>x</sub> amount exhaust from the engine with an engine  
air-fuel ratio; Fig. 3 schematically illustrates a method  
for purifying the exhaust gas according to the present  
invention; Figs. 4A and 4B schematically illustrate the  
35 exhaust gas purifying method in the engine shown in

Fig. 1; Fig. 5 is a time chart for explaining the exhaust gas purifying method in the engine shown in Fig. 1; Figs. 6A and 6B are diagrams illustrating the  $\text{NO}_x$  amount exhausted from the engine per unit time; Fig. 7 is a diagram illustrating the  $\text{NH}_3$  synthesizing efficiency of the  $\text{NH}_3$  synthesizing catalyst; Figs. 8A and 8B are diagrams illustrating the  $\text{NH}_3$  amount desorbed from the  $\text{NH}_3$  adsorbing and oxidizing catalyst per unit time; Figs. 9A and 9B are diagrams illustrating the temperatures of the exhaust gas; Fig. 10 is a flow chart for controlling the engine operation period; Fig. 11 is a flow chart for calculating the fuel injection time; Fig. 12 is a flow chart for controlling the ignition timing; Fig. 13 is a diagram illustrating a cylinder number ratio; Fig. 14 illustrates the lean and rich operation periods with  $\text{RATIO} = 1$ ; Fig. 15 illustrates the lean and rich operation periods with  $\text{RATIO} = 2$ ; Fig. 16 illustrates the lean and rich operation periods with  $\text{RATIO} = 3$ ; Fig. 17 illustrates the lean and rich operation periods with  $\text{RATIO} = 4$ ; Fig. 18 illustrates the relationship between  $\text{RATIO}$  and  $\text{DRATIO}$ ; Fig. 19 illustrates a method for calculating  $\text{DRICH}$ ; Fig. 20 is a flow chart for controlling the engine operation period, using the ratio, according to another embodiment; Fig. 21 illustrates the lean and rich operation periods with  $\text{RATIO} = 2$ , according to further another embodiment; Fig. 22 illustrates the cylinder number ratio, according to another embodiment; Fig. 23 illustrates the lean air-fuel ratio, according to another embodiment; Fig. 24 illustrates the rich air-fuel ratio, according to another embodiment; Figs. 25A and 25B illustrate the rich air-fuel ratio, according to further another embodiment; Figs. 26 to 29 are time charts illustrating the variation in the target air-fuel ratio, according to further another embodiments, respectively; Fig. 30 is a diagram illustrating the changing rate of

the target air-fuel ratio; Fig. 31 is a flow chart for controlling the ignition timing in the embodiment shown in Fig. 26; Fig. 32 is a general view of an engine, according to a further another embodiment; Fig. 33 is a  
5 general view of an engine, according to a further another embodiment; Figs. 34A and 34B is an illustration for explaining the NO<sub>x</sub> occluding and reducing mechanism of the NO<sub>x</sub> occluding and reducing catalyst; Figs. 35A and 35B schematically illustrate the exhaust gas  
10 purifying method in the engine shown in Fig. 33; Figs. 36A and 36B are diagrams illustrating the NO<sub>x</sub> amount released from the NO<sub>x</sub> occluding and reducing catalyst per unit time; Fig. 37 is a diagram illustrating the temperature of the exhaust gas; Fig. 38A is a flow  
15 chart for controlling the engine operation period in the engine shown in Fig. 33; Fig. 38B is a time chart for explaining the exhaust gas purifying method in the engine shown in Fig. 33; Fig. 39 is a general view of an engine, according to further another embodiment; Figs. 40A and  
20 40B schematically illustrate the exhaust gas purifying method in the engine shown in Fig. 39; Figs. 41A and 41B illustrate other embodiments of the structure of the exhaust gas purifying catalyst, respectively; Fig. 42 is a general view of an engine according to a further  
25 another embodiment; Fig. 43A is a time chart for explaining the exhaust gas purifying method in the engine shown in Fig. 42; Fig. 43B schematically illustrates the variation in the exhaust gas air-fuel ratio along the exhaust passage; Figs. 44 and 45 are flow charts for  
30 calculating the fuel injection times of the engine and the auxiliary engine; Fig. 46 is a general view of the engine, according to a further another embodiment; Fig. 47 is a time chart for explaining the exhaust gas purifying method in the engine shown in Fig. 46; Fig. 48  
35 is a general view of the engine, according to a further another embodiment; and Fig. 49 is a time chart for

explaining the exhaust gas purifying method in the engine shown in Fig. 48.

#### BEST MODE FOR CARRYING OUT THE INVENTION

In general, nitrogen oxides  $\text{NO}_x$  includes nitrogen  
5 monoxide  $\text{NO}$ , nitrogen dioxide  $\text{NO}_2$ , dinitrogen tetroxide  $\text{N}_2\text{O}_4$ , dinitrogen monoxide  $\text{N}_2\text{O}$ , etc. The following explanation is made referring  $\text{NO}_x$  mainly as nitrogen monoxide  $\text{NO}$  and/or nitrogen dioxide  $\text{NO}_2$ , but a method and  
10 a device for purifying an exhaust gas of an engine according to the present invention can purify the other nitrogen oxides.

Fig. 1 shows the case where the present invention is applied to an internal engine of the spark ignition type. However, the present invention may be applied to a diesel  
15 engine. Also, the engine shown in Fig. 1 is used for an automobile, for example.

Referring to Fig. 1, an engine body 1, which is a spark-ignition type engine, has four cylinders, i.e., a first cylinder #1, a second cylinder #2, a third  
20 cylinder #3, a fourth cylinder #4. Each cylinder #1 to #4 is connected to a common surge tank 3, via a corresponding branch 2, and the surge tank 3 is connected to a air-cleaner (not shown) via an intake duct 4. In each branch 2, a fuel injector 5 is arranged to feed  
25 fuel, such as gasoline, to the corresponding cylinder. Further, a throttle valve 6 is arranged in the intake duct 4, an opening of which becomes larger as the depression of the acceleration pedal (not shown) becomes larger. Note that the fuel injectors 5 are controlled in  
30 accordance with the output signals from an electronic control unit 20.

On the other hand, each cylinder is connected to a common exhaust manifold 7, and the exhaust manifold 7 is connected to a catalytic converter 9 housing an  $\text{NH}_3$   
35 synthesizing catalyst 8 therein. The catalytic converter 9 is then connected to a muffler 10 housing an

exhaust gas purifying catalyst 10 therein. The muffler 10 is then connected to a catalytic converter 13 housing an  $\text{NH}_3$  purifying catalyst 12 therein. Further, as shown in Fig. 1, a secondary air supplying device 14 is arranged in the exhaust passage between the muffler 11 and the catalytic converter 13, for supplying a secondary air to the  $\text{NH}_3$  purifying catalyst 12, and is controlled in accordance with the output signals from the electronic control unit 20. Further, each cylinder #1 to #4 is provided with a spark plug 15, which is controlled in accordance with the output signals from the electronic control unit 20.

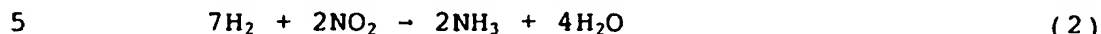
The electronic control unit 20 comprises a digital computer and is provided with a ROM (read only memory) 22, a RAM (random access memory) 23, a CPU (micro processor) 24, an input port 25, and an output port 26, which are interconnected by a bidirectional bus 21. Mounted in the surge tank 3 is a pressure sensor 27 generating an output voltage proportional to a pressure in the surge tank 3. The output voltage of the sensor 27 is input via an AD converter 28 to the input port 25. The intake air amount  $Q$  is calculated in the CPU 24 on the basis of the output signals from the AD converter 28. Further, mounted in the collecting portion of the exhaust manifold 7 is an upstream side air-fuel ratio sensor 29a generating an output voltage proportional to an exhaust gas air-fuel ratio, explained hereinafter, of the exhaust gas flowing through the collecting portion of the exhaust manifold 7. The output voltage of the sensor 29a is input via an AD converter 30a to the input port 25. Mounted in the exhaust passage between the catalytic converter 9 and the muffler 11 is a downstream side air-fuel ratio sensor 29b generating an output voltage proportional to the exhaust gas air-fuel ratio of the exhaust gas flowing in that exhaust passage, that is, exhausted from the  $\text{NH}_3$  synthesizing catalyst 8. The

output voltage of the sensor 29b is input via an AD converter 30b to the input port 25. Further, connected to the input port 25 is a crank angle sensor 31 generating an output pulse whenever the crank shaft of the engine 1 turns by, for example, 30 degrees. The CPU 24 calculates the engine speed N in accordance with the pulse. On the other hand, the output port 26 is connected to the fuel injectors 5, the spark plugs 15, and the secondary supplying device 14, via corresponding drive circuits 32.

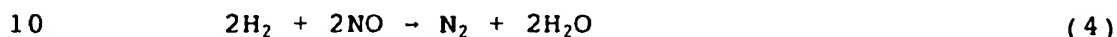
In the embodiment shown in Fig. 1, the  $\text{NH}_3$  synthesizing catalyst 8 is comprised of a three-way catalyst 8a, which is simply expressed as a TW catalyst, here. The TW catalyst 8a is comprised of precious metals such as palladium Pd, platinum Pt, and rhodium Rh, carried on a layer of, for example, alumina, formed on a surface of a substrate.

Fig. 2A illustrates the purifying efficiency of the exhaust gas of the TW catalyst 8a. If a ratio of the total amount of air fed into the intake passage, the combustion chamber, and the exhaust passage upstream of a certain position in the exhaust passage to the total amount of fuel fed into the intake passage, the combustion chamber, and the exhaust passage upstream of the above-mentioned position is referred to as an exhaust gas air-fuel ratio of the exhaust gas flowing through the certain position, Fig. 2A shows that the TW catalyst 8a passes the inflowing  $\text{NO}_x$  therethrough when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean with respect to the stoichiometric air-fuel ratio  $(\text{A/F})_S$ , which is about 14.6 and the air-excess ratio  $\lambda = 1.0$ , and the TW catalyst 8a synthesizes  $\text{NH}_3$  from a part of the inflowing  $\text{NO}_x$  when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich. The  $\text{NH}_3$  synthesizing function of the TW catalyst 8a is unclear, but it can be considered that some of  $\text{NO}_x$  in the exhaust gas of which

the exhaust gas air-fuel ratio is rich is converted to  $\text{NH}_3$  according to the following reactions (1) and (2), that is:



On the contrary, it is considered that the other  $\text{NO}_x$  is reduced to the nitrogen  $\text{N}_2$  according to the following reactions (3) to (6), that is:



Accordingly,  $\text{NO}_x$  flowing in the TW catalyst 8a is converted to either  $\text{NH}_3$  or  $\text{N}_2$  when the exhaust gas  
15 air-fuel ratio of the inflowing exhaust gas is rich, and thus  $\text{NO}_x$  is prevented from being discharged from the TW catalyst 8a.

As shown in Fig. 2A, an efficiency ETA of the  $\text{NH}_3$  synthesizing of the TW catalyst 8a becomes larger as the  
20 exhaust gas air-fuel ratio of the inflowing exhaust gas becomes smaller or richer from the stoichiometric air-fuel ratio (A/F)<sub>S</sub>, and is kept constant when the exhaust gas air-fuel ratio of the inflowing exhaust gas becomes even smaller. In the example shown in Fig. 2A,  
25 the  $\text{NH}_3$  synthesizing efficiency ETA is kept constant when the exhaust gas air-fuel ratio of the inflowing exhaust gas equals or is smaller than about 13.8, where the air-excess ratio  $\lambda$  is about 0.95).

On the other hand, the  $\text{NO}_x$  amount exhausted from  
30 each cylinder per unit time depends on the engine air-fuel ratio, as shown in Fig. 2B. In particular, the exhausted  $\text{NO}_x$  amount becomes smaller as the engine air-fuel ratio becomes smaller when the engine air-fuel ratio is rich. Therefore, considering the synthesizing  
35 efficiency ETA, the  $\text{NH}_3$  amount synthesized in the TW



catalyst 8a per unit time reaches the maximum amount thereof when the exhaust gas air-fuel ratio of the inflowing exhaust gas is about 13.8, if the exhaust gas air-fuel ratio of the inflowing exhaust gas conforms to the engine air-fuel ratio.

Note that, in the engine shown in Fig. 1, it is desired to synthesize  $\text{NH}_3$  in as large amount as possible, when the exhaust gas air-fuel ratio of the exhaust gas flowing the TW catalyst 8a is rich, because of the reasons described below. Accordingly, a TW catalyst carrying palladium Pd or cerium Ce is used as the TW catalyst 8a. In particular, a TW catalyst carrying palladium Pd can also enhance a HC purifying efficiency, when the exhaust air-fuel ratio of the inflowing exhaust gas is rich. Further, note that a TW catalyst carrying rhodium Rh suppresses an  $\text{NH}_3$  synthesizing therein, and a TW catalyst without rhodium Rh is desired used as the TW catalyst 8a.

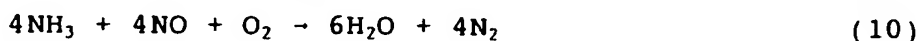
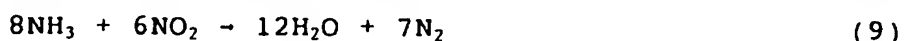
On the other hand, in the embodiment shown in Fig. 1, the exhaust gas purifying catalyst 10 is consisted of an  $\text{NH}_3$  adsorbing and oxidizing catalyst 10a, which is simply expressed as a  $\text{NH}_3$ -AO catalyst. The  $\text{NH}_3$ -AO catalyst 10a is comprised of a so-called zeolite denitration catalyst, such as zeolite carrying copper Cu thereon, zeolite carrying copper Cu and platinum Pt thereon, and zeolite carrying iron Fe thereon, which is carried on a surface of a substrate. Alternatively, the  $\text{NH}_3$ -AO catalyst 10a is comprised of solid acid such as zeolite, silica, silica-alumina, and titania, carrying the transition metals such as iron Fe and copper Cu or precious metals such as palladium Pd, platinum Pt and rhodium Rh.

The  $\text{NH}_3$ -AO catalyst 10a adsorbs  $\text{NH}_3$  in the inflowing exhaust gas, and desorbs the adsorbed  $\text{NH}_3$  when the  $\text{NH}_3$  concentration in the inflowing exhaust gas becomes lower, or when the inflowing exhaust gas includes  $\text{NO}_x$ . At this

time, if the  $\text{NH}_3$ -AO catalyst 10a is under the oxidizing atmosphere, that is, if the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, the  $\text{NH}_3$ -AO catalyst 10a oxidizes all of  $\text{NH}_3$  desorbed therefrom.

5 Also, if the inflowing exhaust gas includes both of  $\text{NH}_3$  and  $\text{NO}_x$ , the  $\text{NH}_3$ -AO catalyst 10a oxidizes  $\text{NH}_3$  by  $\text{NO}_x$ . In these cases, the  $\text{NH}_3$  oxidizing function has a portion which has been unclear, but it can be considered that the  $\text{NH}_3$  oxidation occurs according to the following

10 reactions (7) to (10), that is:



15 The reactions (9) and (10), which are denitration, reduce both of  $\text{NO}_x$  produced in the oxidation reactions (7) and (8), and  $\text{NO}_x$  in the exhaust gas flowing in the  $\text{NH}_3$ -AO catalyst 10a.

20 It has been found, by experiment, that the  $\text{NH}_3$ -AO catalyst 10a of this embodiment performs good oxidation and denitration when the temperature of the inflowing exhaust gas is about 300 to 500°C. On the other hand, in general, the temperature of the exhaust gas passing through the muffler 11 is about 300 to 500°C. Therefore,  
25 in this embodiment, the  $\text{NH}_3$ -AO catalyst 10a is arranged in the muffler 11 to thereby ensure the good performance of the  $\text{NH}_3$ -AO catalyst 10a.

The  $\text{NH}_3$  purifying catalyst 12 is comprised of transition metals such as iron Fe and copper Cu, or  
30 precious metals such as palladium Pd, platinum Pt, and rhodium Rh, carried on a layer of, for example, alumina, formed on a surface of a substrate. The  $\text{NH}_3$  purifying catalyst 12 purifies or resolves  $\text{NH}_3$  in the inflowing exhaust gas, if the catalyst 12 is under the oxidizing  
35 atmosphere, that is, if the exhaust gas air-fuel ratio of

the inflowing exhaust gas is lean. In this case, it is considered that the oxidation and denitration reactions (7) to (10) mentioned above occur in the catalyst 12 and thereby  $\text{NH}_3$  is purified or resolved. In this embodiment, basically, the  $\text{NH}_3$  amount exhausted from the  $\text{NH}_3$ -AO catalyst 10a is kept zero, but the  $\text{NH}_3$  purifying catalyst 12 prevents  $\text{NH}_3$  from being emitted to the ambient air, even if  $\text{NH}_3$  is discharged from the  $\text{NH}_3$ -AO catalyst 10a without being purified.

In the engine shown in Fig. 1, the fuel injection time  $\text{TAU}$  is calculated using the following equation:

$$\text{TAU} = \text{TB} \cdot ((\text{A/F})\text{S} / (\text{A/F})\text{T}) \cdot \text{FAF}$$

$\text{TB}$  represents a basic fuel injection time suitable for making the engine air-fuel ratio of each cylinder equal to the stoichiometric air-fuel ratio  $(\text{A/F})\text{S}$ , and is calculated using the following equation:

$$\text{TB} = (\text{Q} / \text{N}) \cdot \text{K}$$

where  $\text{Q}$  represents the intake air amount,  $\text{N}$  represents the engine speed, and  $\text{K}$  represents a constant.

Accordingly, the basic fuel injection time  $\text{TB}$  is a product of an intake air amount per unit engine speed, and the constant.

$(\text{A/F})\text{T}$  represents a target value for the control of the engine air-fuel ratio. When the target value  $(\text{A/F})\text{T}$  is made larger to make the engine air-fuel ratio lean with respect to the stoichiometric air-fuel ratio, the fuel injection time  $\text{TAU}$  is made shorter and thereby the fuel amount to be injected is decreased. When the target value  $(\text{A/F})\text{T}$  is made smaller to make the engine air-fuel ratio rich with respect to the stoichiometric air-fuel ratio, the fuel injection time  $\text{TAU}$  is made longer and thereby the fuel amount to be injected is increased.

$\text{FAF}$  represents a feedback correction coefficient for making the actual engine air-fuel ratio equal to the target value  $(\text{A/F})\text{T}$ . The feedback correction coefficient  $\text{FAF}$  is determined on the basis of the output signals from

the upstream side air-fuel ratio sensor 29a, mainly. The exhaust gas air-fuel ratio of the exhaust gas flowing through the exhaust manifold 7 and detected by the upstream side air-fuel ratio sensor 29a conforms to the engine air-fuel ratio. When the exhaust gas air-fuel ratio detected by the upstream side sensor 29a is lean with respect to the target value  $(A/F)_T$ , the feedback correction coefficient FAF is made larger and thereby the fuel amount to be injected is increased. When the exhaust gas air-fuel ratio detected by the sensor 29a is rich with respect to the target value  $(A/F)_T$ , FAF is made smaller and thereby the fuel amount to be injected is decreased. In this way, the actual engine air-fuel ratio is made equal to the target value  $(A/F)_T$ . Note that the feedback correction coefficient FAF fluctuates around 1.0.

Contrarily, the downstream side air-fuel ratio sensor 29b is for compensating for the deviation of the engine air-fuel ratio from the target value  $(A/F)_T$  due to the deterioration of the upstream side sensor 29a. For the upstream side and the downstream side sensors 29a and 29b, an air-fuel ratio sensor generating an output voltage which corresponds to the exhaust gas air-fuel ratio over a broader range of the exhaust gas air-fuel ratio may be used, while a Z-output type oxygen concentration sensor, of which an output voltage varies drastically when the detecting exhaust gas air-fuel ratio increases or decreases across the stoichiometric air-fuel ratio, may also be used. Note that the downstream side sensor 29b may be arranged in the exhaust passage between the exhaust gas purifying catalyst 10 and the secondary air supplying device 14, alternatively. Further, the deterioration of the catalyst(s) located between the two sensors 29a and 29b may be detected on the basis of the output signals from the sensors 29a and 29b.

In the engine shown in Fig. 1, there is no device for supplying secondary fuel or secondary air in the

exhaust passage, other than the secondary air supplying device 14. Thus, the engine air-fuel ratio in the exhaust passage upstream of the secondary air supplying device 14 conforms to the engine air-fuel ratio. In other words, the exhaust gas air-fuel ratio of the exhaust gas flowing in the TW catalyst 8a conforms to the engine air-fuel ratio, and the exhaust gas air-fuel ratio of the exhaust gas flowing in the exhaust gas purifying catalyst 10 also conforms to the engine air-fuel ratio. Contrarily, in the exhaust passage downstream of the secondary air supplying device 14, the exhaust gas air-fuel ratio conforms to the engine air-fuel ratio when the supply of the secondary air is stopped, and is made lean with respect to the engine air-fuel ratio when the secondary air is supplied.

Next, the exhaust gas purifying method in the engine shown in Fig. 1 will be explained with reference to Figs. 3, 4A, and 4B.

In the engine shown in Fig. 1, an exhaust gas portion of which the exhaust gas air-fuel ratio is lean, and an exhaust gas portion of which the exhaust gas air-fuel ratio is rich, are formed from the exhaust gas of the engine 1, alternately and repeatedly. Then, the exhaust gas portions are introduced to, in turn, the TW catalyst 8a, the exhaust gas purifying catalyst 10, and the  $\text{NH}_3$  purifying catalyst 12. In other words, the exhaust gas air-fuel ratio of the exhaust gas flowing the catalysts 8a and 10a is made lean and rich alternately and repeatedly, as shown in Fig. 3. When the exhaust gas air-fuel ratio of the inflowing exhaust gas is made rich, the TW catalyst 8a converts  $\text{NO}_x$  in the inflowing exhaust gas to  $\text{NH}_3$  or  $\text{N}_2$ , as shown in Fig. 4A, according to the above-mentioned reactions (1) and (2). The  $\text{NH}_3$  synthesized in the TW catalyst 8a then flows into the  $\text{NH}_3$ -AO catalyst 10a. At this time, the concentration of  $\text{NH}_3$  in the inflowing exhaust gas is relatively high, and

thus almost all of  $\text{NH}_3$  in the inflowing exhaust gas is adsorbed in the  $\text{NH}_3$ -AO catalyst 10a. Even though  $\text{NH}_3$  flows out the  $\text{NH}_3$ -AO catalyst 10a without being adsorbed, the  $\text{NH}_3$  then flows into the  $\text{NH}_3$  purifying catalyst 12 and is purified or oxidized, because the catalyst 12 is kept under the oxidizing atmosphere by the secondary air supplying device 14. In this way,  $\text{NH}_3$  is prevented from being emitted to the ambient air.

Contrarily, when the exhaust gas air-fuel ratio of the inflowing exhaust gas is made lean, the TW catalyst 8a passes the inflowing  $\text{NO}_x$  therethrough, as shown in Fig. 4B, and the  $\text{NO}_x$  then flows into the  $\text{NH}_3$ -AO catalyst 10a. At this time, the  $\text{NH}_3$  concentration in the inflowing exhaust gas is substantially zero, and thus  $\text{NH}_3$  is desorbed from the  $\text{NH}_3$ -AO catalyst 10a. At this time, the  $\text{NH}_3$ -AO catalyst 10a is under the oxidizing atmosphere, and thus the desorbed  $\text{NH}_3$  acts as a reducing agent, and reduces and purifies  $\text{NO}_x$  in the inflowing exhaust gas, according to the above-mentioned reactions (7) to (10). Note that, even if the  $\text{NH}_3$  amount desorbed from the  $\text{NH}_3$ -AO catalyst 10a exceeds over the amount required for reducing the inflowing  $\text{NO}_x$ , the excess  $\text{NH}_3$  is purified or resolved in the  $\text{NH}_3$ -AO catalyst 10a or the  $\text{NH}_3$  purifying catalyst 12. Accordingly,  $\text{NH}_3$  is prevented from being emitted to the ambient air. Note that, in this case, the secondary air is unnecessary.

As mentioned above,  $\text{NO}_x$  exhausted from the engine is reduced to  $\text{N}_2$  or adsorbed in the  $\text{NH}_3$ -AO catalyst 10a in the form of  $\text{NH}_3$  when the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a is rich, and is reduced to  $\text{N}_2$  by  $\text{NH}_3$  desorbed from the  $\text{NH}_3$ -AO catalyst 10a when the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a is

lean. Accordingly, NO<sub>x</sub> is prevented from being emitted to the ambient air, regardless whether the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a is rich or lean.

5           Note that, as mentioned above, it is desired that the NH<sub>3</sub> purifying catalyst 12 is kept under the oxidizing atmosphere to ensure good NH<sub>3</sub> purification. In this embodiment, the secondary air supplying device 14  
10           supplies the secondary air to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the NH<sub>3</sub> purifying catalyst 12 equal to about 15.3 ( $\lambda = 1.05$ ).

          As long as the exhaust gas air-fuel ratio of the exhaust gas flowing into the TW catalyst 8a is kept lean, unburned hydrocarbon HC and/or carbon monoxide, etc. in  
15           the inflowing exhaust gas are oxidized and purified at the TW catalyst 8a. Contrarily, when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich, there may be the case where the HC and/or the CO passes through the TW catalyst 8a and the NH<sub>3</sub>-AO catalyst 10a.  
20           However, the HC and/or the CO then flows into the NH<sub>3</sub> purifying catalyst 12 and are oxidized and purified sufficiently, because the catalyst 12 is kept under the oxidizing atmosphere, as mentioned above.

          To form the exhaust gas portions of which the  
25           exhaust gas air-fuel ratios are lean and rich respectively, there may be provided a secondary air supplying device for supplying the secondary air in, for example, the exhaust manifold 7. In this case, while the engine air-fuel ratio is kept rich, the supply of the  
30           secondary air is stopped to thereby form the exhaust gas portion of which exhaust gas air-fuel ratio is rich, and the secondary air is supplied to thereby form the exhaust gas portion of which exhaust gas air-fuel ratio is lean. Or, there may be provided a secondary fuel supplying  
35           device for supplying the secondary fuel in, for example, the exhaust manifold 7. In this case, while the engine

air-fuel ratio is kept lean, the supply of the secondary fuel is stopped to thereby form the exhaust gas portion of which exhaust gas air-fuel ratio is lean, and the secondary fuel is supplied to thereby form the exhaust gas portion of which exhaust gas air-fuel ratio is rich.

However, as mentioned above, the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a conforms to the engine air-fuel ratio, in the engine shown in Fig. 1. Therefore, the engine air-fuel ratio is controlled to be lean and rich alternately and repeatedly to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean and rich alternately and repeatedly. Namely, the engine 1 operates in a lean engine operation in which the engine air-fuel ratio is lean to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean, and the engine 1 operates in a rich engine operation in which the engine air-fuel ratio is rich to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a rich, and the engine 1 operates in the lean and rich engine operations alternately and repeatedly.

In other words,  $\text{NO}_x$  exhausted from the engine 1 is purified sufficiently and is prevented from being emitted to the ambient air, by the engine operating the lean and rich engine operations alternately and repeatedly.

If a target value of the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a is referred to as a target air-fuel ratio  $(A/F)_T$ , the actual exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a is made equal to the target air-fuel ratio  $(A/F)_T$ , by making the target value of the engine air-fuel ratio equal to the target air-fuel ratio  $(A/F)_T$ . Therefore, in the embodiment, the target value of the engine air-fuel ratio is conformed to



the target air-fuel ratio (A/F)T. The target air-fuel ratio (A/F)T is made equal to a lean air-fuel ratio (A/F)L which is lean with respect to the stoichiometric air-fuel ratio (A/F)S, and equal to a rich air-fuel ratio (A/F)R which is rich with respect to the stoichiometric air-fuel ratio (A/F)S, alternately and repeatedly, to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean and rich alternately and repeatedly. Note that, if an engine operation period during which the engine performs the lean engine operation is referred as a lean operation period TL, and if an engine operation period during which the engine performs the rich engine operation is referred as a rich operation period TR, one lean operation period TL and one rich operation period TR, next to each other, form a cycle.

The lean air-fuel ratio (A/F)L and the rich air-fuel ratio (A/F)R may be determined in accordance with the engine operating condition, respectively. However, in the present embodiment, the lean air-fuel ratio (A/F)L is set constant at about 25.0, and the rich air-fuel ratio (A/F)R is set constant at about 13.8, regardless the engine operating condition. Therefore, the target air-fuel ratio (A/F)T is made equal to about 25.0 when the lean engine operation is to be performed, and is made equal to about 13.8 when the rich engine operation is to be performed.

If the air-fuel mixture spreading over the entire combustion chamber uniformly is formed when the engine air-fuel ratio is very lean, such as 25.0, the spark plug 15 cannot ignite the air-fuel mixture, because the air-fuel mixture is very thin, and misfiring may occur. To solve this, in the engine shown in Fig. 1, an ignitable air-fuel mixture is formed in a restricted region in the combustion chamber and the reminder is filled with only the air or only the air and the EGR gas, and the air-fuel mixture is ignited by the spark plug 15,

when the lean engine operation is to be performed. This prevents the engine from misfiring, even though the engine air-fuel ratio is very lean. Alternatively, the misfiring may be prevented by forming the swirl flow in the combustion chamber, while forming the uniform air-fuel mixture in the combustion chamber.

As mentioned at the beginning, a lower fuel consumption rate is desired, and thus it is desired to make the lean operation period TL as long as possible, and to make the rich operation period TR as short as possible. In particular, it is preferable that TL/TR is equal to or larger than 3, for the lesser fuel consumption rate. However, as the lean operation period TL becomes longer, the  $\text{NH}_3$  amount desorbed from the  $\text{NH}_3$ -AO catalyst 10a becomes smaller. Thus, a longer lean operation period TL may lead to a lack of  $\text{NH}_3$  for purifying  $\text{NO}_x$  in the  $\text{NH}_3$ -AO catalyst 10a, and to the emit  $\text{NO}_x$  to the ambient air without reduction. To solve this, in this embodiment, an  $\text{NH}_3$  amount adsorbed in the  $\text{NH}_3$ -AO catalyst 10a  $S(\text{NH}_3)$  is obtained by obtaining an  $\text{NH}_3$  amount desorbed from the  $\text{NH}_3$ -AO catalyst 10a during the lean engine operation, and the lean engine operation is stopped and the rich engine operation starts when the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  becomes smaller than a predetermined minimum amount  $\text{MIN}(\text{NH}_3)$ . This prevents  $\text{NO}_x$  flowing into the  $\text{NH}_3$ -AO catalyst 10a from being emitted to the ambient air without being reduced.

On the other hand, the shorter rich operation period is preferable. However, if the rich operation period TR is made too short, the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  may be smaller than that required for the sufficient reduction of  $\text{NO}_x$ , and thereby  $\text{NO}_x$  may be discharged without being reduced when the  $\text{NO}_x$  amount inflowing the  $\text{NH}_3$ -AO catalyst 10a increases drastically. Further, too short a rich operation period may lead to frequent changes in the

target air-fuel ratio (A/F)<sub>T</sub> between the lean and rich air-fuel ratios, and thus an undesired deterioration of the drivability may occur. However, if the rich operation period TR becomes longer, the NH<sub>3</sub>-AO catalyst 10a is saturated with NH<sub>3</sub>, and a large amount of NH<sub>3</sub> is discharged therefrom. To solve this, in this embodiment, the NH<sub>3</sub> amount adsorbed in the NH<sub>3</sub>-AO catalyst 10a during the rich engine operation is obtained to thereby obtain the adsorbed NH<sub>3</sub> amount S(NH<sub>3</sub>), and the rich engine operation is stopped and the lean engine operation is started when the adsorbed NH<sub>3</sub> amount S(NH<sub>3</sub>) becomes larger than a maximum amount MAX(NO<sub>x</sub>), which is determined in accordance with the adsorbing capacity of the NH<sub>3</sub>-AO catalyst 10a. In this way, the lean and the rich operation periods TL and TR are determined in accordance with the adsorbed NH<sub>3</sub> amount S(NH<sub>3</sub>) of the NH<sub>3</sub>-AO catalyst 10a, in the present embodiment.

It is difficult to directly find the adsorbed NH<sub>3</sub> amount in the NH<sub>3</sub>-AO catalyst 10a. Therefore, in this embodiment, the adsorbed NH<sub>3</sub> amount is estimated on the basis of the NH<sub>3</sub> amount synthesized in the TW catalyst 8a or flowing into the NH<sub>3</sub>-AO catalyst 10a. In this case, a sensor for detecting the NH<sub>3</sub> amount flowing into the NH<sub>3</sub>-AO catalyst 10a may be arranged in the exhaust passage between the TW catalyst 8a and the NH<sub>3</sub>-AO catalyst 10a. However, in the embodiment, considering the applicability, the synthesized NH<sub>3</sub> amount is estimated on the basis of the NO<sub>x</sub> amount flowing into the TW catalyst 8a, and then the adsorbed NH<sub>3</sub> amount is estimated on the basis of the synthesized NH<sub>3</sub> amount. That is, the synthesized NH<sub>3</sub> amount per unit time becomes larger as the NO<sub>x</sub> amount flowing into the TW catalyst 8a per unit time becomes larger. Also, the synthesized NH<sub>3</sub> amount per unit time becomes larger as the synthesizing

WO 97/17532

PCT/JP96/03205

- 22 -

efficiency ETA becomes higher.

On the other hand, the  $\text{NO}_x$  amount exhausted from the engine per unit time becomes larger as the engine speed  $N$  becomes higher, and thus the  $\text{NO}_x$  amount flowing into the TW catalyst 8a per unit time becomes larger. Also, the exhaust gas amount exhausted from the engine becomes larger and the combustion temperature becomes higher as the engine load  $Q/N$  (the intake air amount  $Q$  / the engine speed  $N$ ) becomes higher, and thus the  $\text{NO}_x$  amount flowing into the TW catalyst 8a per unit becomes larger as the engine load  $Q/N$  becomes higher.

Fig. 6A illustrates the relationships, obtained by experiments, between the  $\text{NO}_x$  amount exhausted from the engine per unit time  $Q(\text{NO}_x)$ , the engine load  $Q/N$ , and the engine speed  $N$ , with a constant lean or rich air-fuel ratio  $(A/F)_L$  or  $(A/F)_R$ . In Fig. 6A, the curves show the identical  $\text{NO}_x$  amount. As shown in Fig. 6A, the exhausted  $\text{NO}_x$  amount  $Q(\text{NO}_x)$  becomes larger as the engine load  $Q/N$  becomes higher, and as the engine speed  $N$  becomes higher. Note that the exhausted  $\text{NO}_x$  amount  $Q(\text{NO}_x)$  is stored in the ROM 22 in advance in the form of a map as shown in Fig. 6B.

The synthesizing efficiency ETA varies in accordance with the temperature TTC of the exhaust gas flowing into the TW catalyst 8a, which represents the temperature of the TW catalyst 8a. That is, as shown in Fig. 7, the synthesizing efficiency ETA becomes higher as the exhaust gas temperature TTC becomes higher when TTC is low, and becomes lower as TTC becomes higher when TTC is high, with the constant rich air-fuel ratio  $(A/F)_R$ . The synthesizing efficiency ETA is stored in the ROM 22 in advance in the form of a map as shown in Fig. 7.

Note that the exhausted  $\text{NO}_x$  amount from the engine per unit time  $Q(\text{NO}_x)$  varies in accordance with the engine air-fuel ratio, as described above with reference to Fig. 2B. Therefore, if the lean or rich air-fuel ratio

(A/F)L, (A/F)R is changed in accordance with, for example, the engine operating condition, the exhausted  $\text{NO}_x$  amount  $Q(\text{NO}_x)$  obtained by the map shown in Fig. 6B must be corrected on the basis of the actual lean or rich air-fuel ratio (A/F)L, (A/F)R. Further, the synthesizing efficiency ETA also varies in accordance with the exhaust gas air-fuel ratio of the exhaust gas flowing into the TW catalyst 8a, that is, the rich air-fuel ratio (A/F)R, as shown in Fig. 2A. Therefore, if the rich air-fuel ratio (A/F)R is changed in accordance with, for example, the engine operating condition, the synthesizing efficiency ETA obtained by the map shown in Fig. 7 is also required to be corrected on the basis of the actual rich air-fuel ratio (A/F)R.

The product of  $Q(\text{NO}_x)$  calculated using the engine load  $Q/N$  and the engine speed  $N$  and the synthesizing efficiency ETA calculated using the exhaust gas temperature TTC represents the  $\text{NH}_3$  amount flowing into the  $\text{NH}_3$ -AO catalyst 10a per unit time. Accordingly, during the rich engine operation, the  $\text{NH}_3$  amount adsorbed in the  $\text{NH}_3$ -AO catalyst 10a is calculated using the following equation:

$$S(\text{NH}_3) = S(\text{NH}_3) + Q(\text{NO}_x) \cdot \text{ETA} \cdot \text{DELTAa}$$

where DELTAa represents the time interval of calculation of  $Q(\text{NO}_x)$  and ETA. Thus,  $Q(\text{NO}_x) \cdot \text{ETA} \cdot \text{DELTAa}$  represents the  $\text{NH}_3$  amount adsorbed in the  $\text{NH}_3$ -AO catalyst 10a from the last calculation of  $Q(\text{NO}_x)$  and ETA until the present calculation.

Fig. 8A illustrates the  $\text{NH}_3$  amount  $D(\text{NH}_3)$  desorbed from the  $\text{NH}_3$ -AO catalyst 10a per unit time, when the exhaust gas air-fuel ratio of the exhaust gas flowing into the  $\text{NH}_3$ -AO catalyst 10a is changed from rich to lean, obtained by experiment. In Fig. 8A, the curves show the identical desorbed  $\text{NH}_3$  amount. As shown in Fig. 8A, the desorbed  $\text{NH}_3$  amount  $D(\text{NH}_3)$  becomes larger as

the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  becomes larger. Also,  $D(\text{NH}_3)$  becomes larger as the temperature TAC of the exhaust gas flowing into the  $\text{NH}_3$ -AO catalyst 10a, which represents the temperature of the  $\text{NH}_3$ -AO catalyst 10a, becomes higher. The desorbed  $\text{NH}_3$  amount  $D(\text{NH}_3)$  is stored in the ROM 22 in advance in the form of a map as shown in Fig. 8B.

Accordingly, during the lean engine operation, the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  is calculated using the following equation:

$$S(\text{NH}_3) = S(\text{NH}_3) - D(\text{NH}_3) \cdot \text{DELTA}d$$

where DELTA $d$  represents the time interval of the calculation of  $D(\text{NH}_3)$ , and thus  $D(\text{NH}_3) \cdot \text{DELTA}d$  represents the  $\text{NH}_3$  amount desorbed from the  $\text{NH}_3$ -AO catalyst 10a, from the last calculation of  $D(\text{NH}_3)$  until the present calculation.

To obtain the temperature TTC of the exhaust gas flowing into the TW catalyst 8a, and the temperature TAC of the exhaust gas flowing into the  $\text{NH}_3$ -AO catalyst 10a, temperature sensors may be arranged in the exhaust passage directly upstream of the TW catalyst 8a and directly upstream of the  $\text{NH}_3$ -AO catalyst 10a, respectively. However, the exhaust gas temperatures can be estimated on the basis of the engine operating condition, that is, the engine load  $Q/N$  and the engine speed  $N$ . Thus, in the engine shown in Fig. 1, TTC and TAC are stored in the ROM 22 in advance in the form of a map as shown in Figs. 9A and 9B. ETA and  $D(\text{NH}_3)$  are calculated using TTC and TAC obtained from the maps shown in Figs. 9A and 9B.

In this embodiment, one lean operation period TL is performed for several minutes, and one rich operation period is performed for several seconds, for example. Therefore, in this embodiment, the engine 1 performs the lean engine operation basically, and performs the rich

engine operation temporarily. In this case, a plurality of cylinders perform the lean engine operation during the lean engine operation, and a plurality of cylinders perform the rich engine operation during the rich engine operation. Note that the lean and the rich operation periods may be predetermined as a time. Further, alternatively, first, the total NO<sub>x</sub> amount flowing into the NH<sub>3</sub>-AO catalyst 10a during the lean engine operation may be found, and the lean operation period TL may be set so that the total inflowing NO<sub>x</sub> amount does not exceed a NO<sub>x</sub> amount which NH<sub>3</sub> adsorbed in the NH<sub>3</sub>-AO catalyst 10a can purify.

Next, the control of the ignition timing in the engine shown in Fig. 1 will be explained with reference to Fig. 5.

In the engine shown in Fig. 1, the ignition timing IT in the lean engine operation is made ITL which provides, for example, the suitable output torque of the engine. On the contrary, the ignition timing IT in the rich engine operation is made ITR which is retarded with respect to the ignition timing ITL. Retarding the ignition timing suppresses the increase of the output torque, and thereby suppresses the undesired fluctuation in the output torque when the engine performs the lean and rich engine operations alternately and repeatedly. Further, retarding the ignition timing increases the temperature of the exhaust gas flowing into the TW catalyst 8a, and thereby the synthesized NH<sub>3</sub> amount is kept larger. As a result, the NH<sub>3</sub> amount for purifying NO<sub>x</sub> increases without extending the rich operation period TR. Note that the ignition timing in the lean engine operation ITL is set in accordance with the engine operating condition, such as the lean air-fuel ratio (A/F)<sub>L</sub>. Also, the ignition timing in the rich engine operation ITR is set in accordance with the engine operating condition, such as the rich air-fuel ratio

(A/F)R and the ignition timing ITL.

Figs. 10 to 12 illustrate routines for executing the above-mentioned embodiment. Each routine is executed by interruption every predetermined crank angle.

5 Fig. 10 illustrates a routines for executing the control of the engine operation periods.

Referring to Fig. 10, first, in step 40, it is judged whether FRICH is made 1. FRICH is made 1 when the rich operation is to be performed, and is made zero when  
10 the lean operation is to be performed. If FRICH is 1, that is, if the rich operation is to be performed, the routine goes to step 41, where the exhausted  $\text{NO}_x$  amount  $Q(\text{NO}_x)$  is calculated using the map shown in Fig. 6B on the basis of the engine load  $Q/N$  and the engine speed  $N$ .  
15 In the following step 42, the exhaust gas temperature  $\text{TTC}$  is calculated using the map shown in Fig. 9A. In the following step 43, the  $\text{NH}_3$  synthesizing efficiency  $\text{ETA}$  is calculated using the map shown in Fig. 7 on the basis of the exhaust gas temperature  $\text{TTC}$ . In the following  
20 step 44, the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  is calculated using the following equation:

$$S(\text{NH}_3) = S(\text{NH}_3) + Q(\text{NO}_x) \cdot \text{ETA} \cdot \text{DELTAa}$$

where  $\text{DELTAa}$  is a time interval from the last processing cycle until the present processing cycle, and is obtained  
25 by, for example, a timer. In the following step 45, it is judged whether the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  is larger than the maximum amount  $\text{MAX}(\text{NH}_3)$ . If  $S(\text{NH}_3) \leq \text{MAX}(\text{NH}_3)$ , the processing cycle is ended. Namely, if  $S(\text{NH}_3) \leq \text{MAX}(\text{NH}_3)$ , the adsorbed  $\text{NH}_3$  amount is judged to be  
30 too small to purify  $\text{NO}_x$ , and thus the rich operation is continuously performed.

If  $S(\text{NH}_3) > \text{MAX}(\text{NH}_3)$ , the routine goes to step 46, where FRICH is made zero, and then the processing cycle is ended. Namely, if  $S(\text{NH}_3) > \text{MAX}(\text{NH}_3)$ , the adsorbed  $\text{NH}_3$   
35 amount is sufficient to purify  $\text{NO}_x$ , and the rich



operation is stopped and the lean operation starts (as at the time a, c, e, or g shown in Fig. 5). Accordingly, the rich operation period TR is a period from when FRICH is made 1 until  $S(\text{NH}_3) > \text{MAX}(\text{NH}_3)$ .

5 Contrarily, if  $\text{FRICH} = 0$  in step 40, that is, if the lean operation is to be performed, the routine goes to step 47, where the exhaust gas temperature TAC is calculated using the map shown in Fig. 7B. In the following step 48, the desorbed  $\text{NH}_3$  amount  $D(\text{NH}_3)$  is  
10 calculated using the map shown in Fig. 8B, on the basis of TAC and the present  $S(\text{NH}_3)$ . In the following step 49, the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  is calculated using the following equation:

$$S(\text{NH}_3) = S(\text{NH}_3) - D(\text{NH}_3) \cdot \text{DELTA}d$$

15 where DELTAd is a time interval from the last processing cycle until the present processing cycle. In the following step 50, it is judged whether the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  is smaller than the minimum amount  $\text{MIN}(\text{NH}_3)$ . If  $S(\text{NH}_3) \geq \text{MIN}(\text{NH}_3)$ , the processing cycle is  
20 ended. Namely, if  $S(\text{NH}_3) \geq \text{MIN}(\text{NH}_3)$ , the adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  is judged to be still large to purify  $\text{NO}_x$ , and thus the lean operation is continued.

If  $S(\text{NH}_3) < \text{MIN}(\text{NH}_3)$ , the routine goes to step 51, FRICH is made 1 and the processing cycle is ended.  
25 Namely, if  $S(\text{NH}_3) < \text{MIN}(\text{NH}_3)$ , the adsorbed  $\text{NH}_3$  amount is judged to be insufficient to purify  $\text{NO}_x$ , and thus the lean operation is stopped and the rich engine operation starts (as at the time b, d, or f shown in Fig. 5). Accordingly, the lean operation period TL is from when  
30 the FRICH is made zero until  $S(\text{NH}_3) < \text{MIN}(\text{NH}_3)$ .

Fig. 11 illustrates the routine for calculating the fuel injection time TAU.

Referring to Fig. 11, first, in step 60, the basic fuel injection time TB is calculated using the following  
35 equation, on the basis of the engine load Q/N and the

engine speed N:

$$TB = (Q / N) \cdot K$$

In the following step 61, the feedback correction coefficient FAF is calculated. In the following step 62, it is judged whether FRICH, which is controlled in the routine shown in Fig. 10, is made 1. If FRICH = 1, that is, if the rich operation is to be performed, the routine goes to step 63, where the rich air-fuel ratio (A/F)R is calculated. In this embodiment, the rich air-fuel ratio (A/F)R is kept constant at 13.8 regardless the engine operating condition, and thus the rich air-fuel ratio (A/F)R is made 13.8 in step 63. In the following step 64, the rich air-fuel ratio (A/F)R is memorized as the target air-fuel ratio (A/F)T. Next, the routine goes to step 65.

Contrarily, if FRICH is zero, that is, if the lean operation is to be performed, the routine goes to step 66, where the lean air-fuel ratio (A/F)L is calculated. In this embodiment, the lean air-fuel ratio (A/F)L is kept constant at 25.0 regardless the engine operating condition, and thus the lean air-fuel ratio (A/F)L is made 25.0 in step 66. In the following step 67, the lean air-fuel ratio (A/F)L is memorized as the target air-fuel ratio (A/F)T. Next, the routine goes to step 65.

In step 65, the fuel injection time TAU is calculated using the following equation:

$$TAU = TB \cdot ((A/F)S / (A/F)T) \cdot FAF$$

Each fuel injector 5 injects the fuel for the fuel injection time TAU.

Fig. 12 illustrates a routine for executing the control of the ignition timing.

Referring to Fig. 12, first, in step 160, it is judged whether FRICH, which is controlled in the routine shown in Fig. 10, is made zero. If FRICH = 0, that is, if the lean operation is to be performed, the routine goes to step 161, where ITL is calculated in accordance

with, for example, the engine operating condition. In the following step 162, ITL is memorized as the ignition timing IT. Then, the processing cycle is ended.

5 If FRICH = 1 in step 160, that is, if the rich operation is to be performed, the routine goes to step 163, where ITR is calculated in accordance with, for example, ITL. In the following step 164, ITR is memorized as the ignition timing IT. Then, the processing cycle is ended. Each spark plug 15 performs the igniting operation in accordance with the ignition timing ITL or ITR.

10 In the embodiment mentioned above, the exhaust gas can be purified sufficiently using a single exhaust passage, that is, without providing a plurality of the exhaust passages. Accordingly, the structure of the exhaust gas purifying device is kept small and simple.

15 On the other hand, if a ratio of the number of the cylinders which performs the lean engine operation to the number of the cylinders which performs the rich engine operation in one cycle (see Fig. 5) is referred as a cylinder number ratio RATIO, it is desired to make the cylinder number ratio RATIO as large as possible, to thereby make the fuel consumption rate as small as possible. However, if a part of the cylinders performs the rich engine operation and the other performs the lean engine operation as in the prior art device mentioned at the beginning, the cylinder number ratio RATIO is limited. That is, in the four-cylinder engine, for example, the ratio RATIO is limited to 3 and cannot be made larger than 3. Thus, the decrease of the fuel consumption rate is limited, with the identical lean and rich air-fuel ratio (A/F)<sub>L</sub> and (A/F)<sub>R</sub>. Contrarily, in the embodiment, the ratio RATIO is allowed to be made larger until the NO<sub>x</sub> amount flowing into the NH<sub>3</sub>-AO catalyst 10a exceeds the NH<sub>3</sub> amount desorbed from the catalyst 10a. In particular, the cylinder number ratio

RATIO is made larger than 3 in the four-cylinders engine. As a result, the fuel consumption rate is made more lower.

Further, if the first cylinder #1 continuously performs the rich operation and the second, third, and fourth cylinders #2, #3, #4 continuously perform the lean operation, for example, as in the prior art, a large temperature difference between the exhaust gases exhausted from the cylinders #1 to #4 may occur, and may lead a larger temperature drop in the engine body or in the exhaust manifold 7, to thereby lead to a large thermal distortion therein. Furthermore, in this example, a large amount of the deposition may exist in the first cylinder #1 which performs the rich operation continuously. Contrarily, in this embodiment, a cylinder in which the lean or rich operation is to be performed is not specified, that is, every cylinder performs both the lean and the rich operations. Accordingly, a large thermal distortion in the engine body or in the exhaust manifold 7 is prevented, and the large amount of the deposition on the particular cylinder is also prevented.

Additionally, the exhaust gas purifying method according to the present embodiment may be used in a single cylinder engine.

Next, another embodiment for determining the lean and the rich operation period  $TL$ ,  $TR$ , in the engine shown in Fig. 1, will be explained.

In the above-mentioned embodiment, the lean and the rich operation period  $TL$ ,  $TR$  are set in accordance with the adsorbed  $NH_3$  amount  $S(NH_3)$ . As a result, the cylinder number ratio  $RATIO$  is set in accordance with the adsorbed  $NH_3$  amount  $S(NH_3)$ . Contrarily, in this embodiment, a ratio  $RATIO$  suitable for purifying  $NO_x$  for every engine operating condition is stored in advance, and the lean and the rich operation period  $TL$  and  $TR$  are set to make the actual cylinder number ratio equal to

this suitable ratio **RATIO**.

In this embodiment, the ratio **RATIO** is one selected from 1, 2, 3, and 4. Fig. 13 shows the ratio **RATIO** suitable for purifying  $\text{NO}_x$  for an engine operating  
5 condition defined by the engine load  $Q/N$  and the engine speed  $N$ . As shown in Fig. 13, the ratio **RATIO** becomes larger as the engine load  $Q/N$  become higher when the engine load  $Q/N$  is low, and becomes smaller as the engine load  $Q/N$  becomes higher when the engine load  $Q/N$  is high,  
10 with the constant engine speed  $N$ . The ratio **RATIO** is stored in the ROM 22 in advance in the form of a map as shown in Fig. 13.

For the ratio **RATIO** obtained from the map shown in Fig. 13, any method can be applied to set the number of  
15 the cylinders performing the lean engine operation and that performing the rich engine operation. In this embodiment, the number of the cylinder performing the rich engine operation is set to 1 regardless the ratio **RATIO**. As mentioned above, the ratio **RATIO** is a ratio of  
20 the number of the cylinders performing the lean engine operation to that performing the rich engine operation, in one cycle. Thus, the number of the cylinders performing the lean engine operation is made 1, 2, 3, and 4, for the ratio **RATIO** 1, 2, 3, and 4, respectively, with  
25 the number of cylinder performing the rich engine operation being 1. Next, the method for controlling the engine operation period will be explained in more detail, with reference to Figs. 14 to 17.

In the engine shown in Fig. 1, the combustion stroke  
30 of one of the cylinders is in process whenever the crankshaft turns by about 180 degree. That is, the combustion strokes are in process repeatedly in the order of the first #1, the third #3, the fourth #4, and the second cylinder #2. In Figs. 14 to 17, white and black  
35 circles represent the lean and the rich engine operations, respectively. Fig. 14 illustrates the case

in which the ratio  $RATIO$  is made 1. In this case, the rich operation is performed in one cylinder, that is, for example, the first cylinder #1, and the lean operation is performed in one cylinder, that is, the third cylinder #3. Thus, the rich operation in the first cylinder #1 forms the rich operation period  $TR$ , and the lean operation in the third cylinder #3 forms the lean operation period  $TL$ , and the operations in the two cylinders form the cycle. The following cycle is formed by the operations of the fourth and the second cylinders #4 and #2.

As mentioned above, in the engine shown in Fig. 1, the combustion stroke is in process whenever the crankshaft turns by about 180 degree, and thus the exhaust stroke periods of the cylinders are different from each other, that is, do not overlap each other. As a result, in the case of  $RATIO = 1$ , the exhaust gas exhausted from the first cylinder #1 of which exhaust gas air-fuel ratio is rich first flows into the TW catalyst 8a, and then the exhaust gas exhausted from the third cylinder #3 of which exhaust gas air-fuel ratio is lean flows into the TW catalyst 8a, and, in this manner, the exhaust gases from the cylinders flow into the TW catalyst 8a, in turn. Accordingly, the exhaust gas portions of which the exhaust gas air-fuel ratios are rich and lean flow into the TW catalyst 8a alternately and repeatedly. Note that the present invention may be applied in the case in which the exhaust stroke periods slightly overlap to each other.

Fig. 15 shows the case where  $RATIO = 2$ . In this case, the rich operation is performed in, for example, the first cylinder #1, and the lean operation is performed in two cylinders, that is, the third and the fourth cylinders #3 and #4. Thus, the rich operation in the first cylinder #1 forms the rich operation period  $TR$ , and the lean operations in the third and the fourth cylinders #3 and #4 form the lean operation period  $TL$ ,

and the operations in the three cylinders form the cycle. The following cycle is formed by the operations of the second, the first, and the third cylinders #2, #1, and #3.

5           Fig. 16 shows the case where  $RATIO = 3$ . In this case, the rich operation is performed in, for example, the first cylinder #1, and the lean operation is performed in three cylinders, that is, the third, the fourth, and the second cylinders #3, #4, and #2. Thus, 10 the rich operation in the first cylinder #1 forms the rich operation period  $TR$ , and the lean operations in the third, the fourth, and the second cylinders #3, #4, and #2 form the lean operation period  $TL$ , and the operations in the four cylinders form the cycle. The 15 following cycle is formed by the operation of the first, the third, and the fourth cylinders #1, #3, and #4.

          Fig. 17 shows the case where  $RATIO = 4$ . In this case, the rich operation is performed in, for example, the first cylinder #1, and the lean operation is 20 performed in four cylinders, that is, the third, the fourth, the second, and the first cylinders #3, #4, #2, and #1. Thus, the rich operation in the first cylinder #1 forms the rich operation period  $TR$ , and the lean operations in the third, the fourth, the second, and 25 the first cylinders #3, #4, #2, and #1 form the lean operation period  $TL$ , and the operations in the five cylinders form the cycle. The following cycle is formed by the operation of the third, the fourth, the second, the first, and the third cylinders #3, #4, #2, #1, 30 and #3.

          When the ratio  $RATIO$  is made equal to or larger than the total number of the cylinders of the engine as in the example shown in Fig. 17, all of the cylinders performs the lean engine operation in one lean operation period. 35 This ensures the longer lean operation period  $TL$ , to thereby decrease the fuel consumption rate.

          When setting the cylinder number ratio  $RATIO$  to

thereby set the lean and the rich operation periods TL and TR in this way, the  $\text{NH}_3$  amount and the  $\text{NO}_x$  amount flowing into the  $\text{NH}_3$ -AO catalyst 10a can be controlled accurate. This results in preventing  $\text{NO}_x$  and  $\text{NH}_3$  from  
5 passing through the  $\text{NH}_3$ -AO catalyst 10a, and in purifying the exhaust gas sufficiently.

A cylinder performing the rich operation is not fixed when setting the ratio RATIO to thereby set the lean and the rich operation periods TL and TR. Further,  
10 a cylinder performing the rich operation varies in every cycle, when the ratio RATIO is made 2 or 4, for example. Thus, the engine body 1 or the exhaust manifold 7 is further prevented from the thermal distortion, and the deposition in the specific cylinder is further prevented.

15 Note that the cylinder performing the rich operation is fixed when the ratio is made 1 or 3, as shown in Fig. 14 or 16. Namely, only the first and the third cylinders #1 and #3 perform the rich operation in the example shown in Fig. 14, and only the first cylinder #1  
20 performs the rich operation in the example shown in Fig. 16. However, if the ratio RATIO changes due to the change in the engine operating condition, the cylinder performing the rich operation is changed. Namely, the cylinder performing the rich operation changes whenever  
25 the ratio RATIO changes, and thus the cylinder is not necessarily fixed. Note that, if the ratio RATIO is kept identical for a long period due to the stable engine operating condition and thereby a specific cylinder performs the rich operation for a predetermined period,  
30 the cylinder performing the rich operation may be changed to the other while keeping the ratio RATIO. Namely, in the example shown in Fig. 16, if the first cylinder #1 performs the rich operation for the predetermined period, the third cylinder #3 performs the rich operation, while  
35 the first cylinder performs the lean operation to keep the ratio RATIO, for example. Alternatively, the ratio



RATIO may be changed to 2 or 4 temporarily, to thereby change the cylinder performing the rich operation.

When the lean and the rich operations are performed in accordance with the ratio RATIO, each cylinder is  
5 required to be judged whether it has to perform the lean operation or the rich operation. Next, the method for judging whether the cylinder has to perform the lean operation or the rich operation will be explained.

In this embodiment, the product DRICH of the data  
10 DRATIO of 5 bits representing the cylinder number ratio RATIO, and the history data DHISTORY of 5 bits representing the engine operations in the last five cylinders is calculated whenever the combustion stroke is in process, and it is judged whether the lean operation  
15 or the rich operation is to be performed, on the basis of the product DRICH. The data DRATIO is "00001" for RATIO = 1, "00011" for RATIO = 2, "00111" for RATIO = 3, and "01111" for RATIO = 4, as shown in Fig. 18, and is stored in the ROM 22 in advance in the form of a map as  
20 shown in Fig. 18.

The bit in  $2^4$  of DHISTORY represents the engine operation performed five times before, the bit in  $2^3$  represents the engine operation performed four times before, the bit in  $2^2$  represents the engine operation  
25 performed three times before, the bit in  $2^1$  represents the engine operation performed two times before, and the bit in  $2^0$  represents the last engine operation. In each cylinder, each bit is made zero when the lean operation is performed, and is made 1 when the rich operation is  
30 performed. Thus, DHISTORY = "10010", for example, represents that the rich, the lean, the lean, the rich, and the lean operations have been performed, in turn.

The product DRICH of DRATIO and DHISTORY is calculated when the fuel injection time TAU for each  
35 cylinder is calculated. The cylinder performs the rich operation when DRICH is "00000", and performs the lean

operation when DRICH is the other. Next, an example of DRICH will be explained with reference to Fig. 19, as well as Fig. 15.

Fig. 19 illustrates the product DRICH in the case in which  $RATIO = 2$ . In the example shown in Fig. 19, for the second cylinder #2, DHISTORY is "10010" and DRATIO is "00011", and thus DRICH is "00010". As a result, the second cylinder #2 performs the lean operation. That is, the target air-fuel ratio  $(A/F)_T$  for the second cylinder #2 is made the lean air-fuel ratio  $(A/F)_L$ . For the following first cylinder #1, DHISTORY is "00100" and DRATIO is "00011", and thus DRICH is "00000". As a result, the first cylinder #1 performs the rich operation. That is, the target air-fuel ratio  $(A/F)_T$  for the first cylinder #1 is made the rich air-fuel ratio  $(A/F)_R$ . The following third cylinder #3 performs the lean operation because DRICH is "00001", the following fourth cylinder #4 performs the lean operation because DRICH is "00010", and the following second cylinder #2 performs the rich operation because DRICH is "00000".

Fig. 20 shows a routine for executing the embodiment mentioned above. This routine is executed by interruption every predetermined crank angle.

Referring to Fig. 20, first, in step 70, it is judged whether it is in the fuel injection timing of any one of the cylinders. If it is not in the fuel injection timing, the processing cycle is ended. If it is in the fuel injection timing, the routine goes to step 71, where the cylinder number ratio  $RATIO$  is calculated using the map shown in Fig. 13. In the following step 72, DRATIO is calculated using the map shown in Fig. 18, on the basis of the ratio  $RATIO$  obtained in the step 71. In the following step 73, DRICH is calculated as the product of proposition of DRATIO and DHISTORY. In the following step 74, DHISTORY is renewed on the basis of DRICH in the present processing cycle. In the following step 75, it is judged whether DRICH is "00000". If  $DRICH = "00000"$ ,

the routine goes to step 76, where FRICH is made 1. FRICH is identical one shown in the routine shown in Fig. 10, and the rich engine operation is performed when FRICH is made 1, as can be seen from the routine shown in Fig. 11. Then, the processing cycle is ended.

5 If DRICH \* "00000" in step 75, the routine goes to step 77, where FRICH is made zero. When FRICH is made zero, the lean operation is performed. Then, the processing cycle is ended.

10 In this embodiment, the number of the cylinders performing the rich engine operation in one rich operation period is made 1. As a result, the NH<sub>3</sub> amount flowing into the NH<sub>3</sub>-AO catalyst 10a during one rich operation period is made smaller. Therefore, the volume of the NH<sub>3</sub>-AO catalyst 10a, as well as the size thereof, can be made very small.

Note that, in one cycle, a plurality of cylinders may perform the rich operation. Referring to Fig. 21 which illustrates an example in which the number of the cylinders performing the rich operation in one cycle is made 3, the first, the third, and the fourth cylinders #1, #3, and #4 perform the rich operation, in turn. Then, if the ratio RATIO is made 2, the following six cylinders perform the lean operation. In the following cycle, the third, the fourth, and the second cylinders #3, #4, and #2 perform the rich operation, in turn. In this case, it is prevented that the cylinders performing the rich operation are completely identical to those in the last cycle. That is, the cylinders performing the rich operation vary in every cycle. As a result, in the example shown in Fig. 21, the engine body, for example, is prevented from the thermal distortion, and a large amount of deposition on a specific cylinder is also prevented.

30 In the above-mentioned embodiment, the cylinder number ratio RATIO is set as a function of the engine

WO 97/17532

PCT/JP96/03205

- 38 -

load  $Q/N$  and the engine speed  $N$ . Alternatively, the ratio  $RATIO$  may be set as a function of the intake air amount  $Q$ , as shown in Fig. 22. In this case, the ratio  $RATIO$  becomes larger as the intake air amount  $Q$  becomes larger when  $Q$  is small, and becomes smaller as  $Q$  becomes larger when  $Q$  is large, as shown in Fig. 22.

Next, another method for setting the lean air-fuel ratio  $(A/F)L$  will be explained.

During the lean operation in which the engine air-fuel ratio is made the lean air-fuel ratio  $(A/F)L$ , it is often difficult to ensure the adequate output torque of the engine, and the actual output torque may deviate from the required output torque which is determined in accordance with the engine operating condition, if the target air-fuel ratio  $(A/F)T$  is simply made lean. To solve this, in this embodiment, the lean air-fuel ratio  $(A/F)L$ , which make the actual output torque equal to the required torque in the lean operation, is stored in advance, and the target air-fuel ratio  $(A/F)T$  is set to this lean air-fuel ratio  $(A/F)L$  in the lean operation.

Fig. 23 shows the lean air-fuel ratio  $(A/F)L$  making the actual output torque equal to the required output torque. As shown in Fig. 23, the lean air-fuel ratio  $(A/F)L$  is obtained, as a function of the engine load  $Q/N$  and the engine speed  $N$ , in advance, by experiment. The lean air-fuel ratio  $(A/F)L$  becomes larger as the engine load  $Q/N$  becomes higher when the engine load  $Q/N$  is low, and becomes smaller as the engine load  $Q/N$  becomes higher when the engine load  $Q/N$  is high, with a constant engine speed  $N$ . Further, the lean air-fuel ratio  $(A/F)L$  is stored in the ROM 22 in advance in the form of a map of shown in Fig. 23. The lean air-fuel ratio  $(A/F)L$  may be calculated using the map shown in Fig. 23, in the step 66 in the routine shown in Fig. 11.

Next, another method for setting the rich air-fuel ratio  $(A/F)R$  will be explained.

As mentioned above, shorter rich operation period is

desirable for a lower fuel consumption rate. Thus, it is desired to change the rich air-fuel ratio  $(A/F)_R$  in accordance with the engine operating condition, to thereby make the  $NH_3$  amount synthesized in the rich operation period larger. However, if the  $NH_3$  amount flowing into the  $NH_3$ -AO catalyst 10a suddenly increases when the engine air-fuel ratio changes from the lean air-fuel ratio  $(A/F)_L$  to the rich air-fuel ratio  $(A/F)_R$ , the  $NH_3$  may be discharged from the  $NH_3$ -AO catalyst 10a without being adsorbed. Therefore, in this embodiment, the rich air-fuel ratio  $(A/F)_R$ , which makes the  $NH_3$  amount flowing into the  $NH_3$ -AO catalyst 10a in the rich operation suitable for the decreasing the fuel consumption rate and for good purification of the exhaust gas, is stored in advance, and the target air-fuel ratio  $(A/F)_T$  is made equal to the rich air-fuel ratio  $(A/F)_R$ , in the rich operation.

Fig. 24 shows the rich air-fuel ratio  $(A/F)_R$  making the  $NH_3$  amount flowing into the  $NH_3$ -AO catalyst 10a in the rich operation suitable for the decreasing the fuel consumption rate and for good purification of the exhaust gas. As shown in Fig. 24, the rich air-fuel ratio  $(A/F)_R$  is stored as a function of the intake air amount  $Q$ , in advance, by experiment. The rich air-fuel ratio  $(A/F)_R$  is made 14.4 when  $Q < Q_1$ , becomes smaller as the intake air amount  $Q$  becomes larger when  $Q_1 < Q < Q_2$ , and is made 12.5 when  $Q_2 < Q$ , where  $Q_1$  and  $Q_2$  are predetermined values. When the intake air amount  $Q$  becomes larger and thus the combustion temperature becomes higher, the  $NO_x$  amount exhausted from the engine becomes larger suddenly and thus the  $NH_3$  amount flowing into the  $NH_3$ -AO catalyst 10a becomes larger suddenly. Therefore, when the rich air-fuel ratio  $(A/F)_R$  is made larger and thereby the combustion temperature is lowered,  $NH_3$  is prevented from excessively flowing into the  $NH_3$ -AO catalyst 10a.

Note that the rich air-fuel ratio (A/F)R is stored in the ROM 22 in advance in the form of the map as shown in Fig. 24. The rich air-fuel ratio (A/F)R may be calculated using the map shown in Fig. 24, in the step 63 in the routine shown in Fig. 11.

Next, a further embodiment for setting the rich air-fuel ratio (A/F)R will be explained with reference to Figs. 25A and 25B.

As mentioned above, the engine shown in Fig. 1 mainly performs the lean operation, and performs the rich operation temporarily. Thus, it is desired that the engine performs the rich operation suitable for the lean operation which is a basic engine operation. In other words, it is desired that the engine performs the rich operation to make the synthesized  $\text{NH}_3$  amount thereby equal to that suitable for purifying  $\text{NO}_x$  flowing into the  $\text{NH}_3$ -AO catalyst 10a in the lean operation. Therefore, in this embodiment, a changing value DROP in the target air-fuel ratio (A/F)T making the rich operation suitable for the last lean operation is stored in advance, and the rich air-fuel ratio (A/F)R is calculated by subtracting the changing value DROP from the lean air-fuel ratio (A/F)L in the last lean operation, as shown in Fig. 25A. The changing value DROP varies in accordance with the engine operating condition, and is thus set in accordance with the engine operating condition just before the rich operation in question starts, such as an engine load. This results in purifying the exhaust gas sufficiently, regardless the lean air-fuel ratio (A/F)L.

Fig. 25B shows the changing value DROP obtained in advance by experiment. As shown in Fig. 25B, the changing value DROP becomes smaller as the engine load Q/N becomes higher, and is stored in the ROM 22 in advance in the form of a map as shown in Fig. 25B. In the step 63 in the routine shown in Fig 11, first the changing value DROP may be calculated using the map shown

in Fig. 25B, and then the rich air-fuel ratio (A/F)R may be calculated by subtracting DROP from the lean air-fuel ratio (A/F)L calculated in the step 66.

5 Alternatively, the rich air-fuel ratio (A/F)R may be a standard value, and the lean air-fuel ratio (A/F)L may be calculated by adding a changing value to the rich air-fuel ratio (A/F)R, to thereby make the lean operation suitable for the last rich operation.

10 Next, another embodiment for controlling the target air-fuel ratio (A/F)T for each cylinder will be explained with reference to Figs. 26 to 30.

15 In the above-mentioned embodiments, the target air-fuel ratio (A/F)T of the cylinders is made the lean and the rich air-fuel ratios (A/F)L and (A/F)R alternately and repeatedly to make the exhaust air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean and rich alternately and repeatedly, as shown in Fig. 5. Also, in the above-mentioned embodiments, the target air-fuel ratio is changed in the form of the step.  
20 However, if the target air-fuel ratio is changed in the form of the step, there may occur a drastic change in the output torque of the engine, which is undesirable, and the drivability may deteriorate. Thus, in this embodiment, as shown in Fig. 26, the target air-fuel  
25 ratio (A/F)T is made smaller from the lean air-fuel ratio (A/F)L such as 25.0 to the rich air-fuel ratio (A/F)R such as 13.8 gradually with a predetermined changing rate SLOPER, and is made larger from the rich air-fuel ratio (A/F)R to the lean air-fuel ratio (A/F)L with a  
30 predetermined changing rate SLOPEL. The rates SLOPER and SLOPEL are set in accordance with the engine operating condition, respectively. This prevents a drastic change in the output torque, and ensures the good drivability.

35 In the embodiment shown in Fig. 27, the target air-fuel ratio (A/F)T is also made smaller gradually with the changing rate SLOPER, and is also made larger gradually with the changing rate SLOPEL. This ensures good

drivability. Further, in this embodiment, the target air-fuel ratio (A/F)<sub>T</sub> is kept constant at the lean air-fuel ratio (A/F)<sub>L</sub>, for a predetermined period, after the target air-fuel ratio (A/F)<sub>T</sub> reaches the lean  
5 air-fuel ratio (A/F)<sub>L</sub>, and then is made smaller with the rate SLOPER toward the rich air-fuel ratio (A/F)<sub>R</sub>. As a result, the lean operation period TL is made longer than that in the embodiment shown in Fig. 26, and the fuel consumption rate is made further smaller. Additionally,  
10 the changing operation of the target air-fuel ratio (A/F)<sub>T</sub> between the lean and the rich air-fuel ratios per unit time is made smaller, and thereby the drivability is further enhanced.

As mentioned above, the TW catalyst 8a synthesizes  
15 NH<sub>3</sub> for purifying NO<sub>x</sub> in the rich operation. However, if the target air-fuel ratio (A/F)<sub>T</sub> is made smaller gradually from the lean air-fuel ratio (A/F)<sub>L</sub> to the rich air-fuel ratio (A/F)<sub>R</sub>, the NH<sub>3</sub> amount synthesized in the TW catalyst 8a may not increase quickly, or the NH<sub>3</sub>-AO  
20 catalyst 10a may desorb NH<sub>3</sub> excessive to NO<sub>x</sub> flowing into the catalyst 10a. Thus, in the embodiment shown in Fig. 28, the target air-fuel ratio (A/F)<sub>T</sub> is changed from the lean air-fuel ratio to the rich air-fuel ratio quickly in the form of the step, to thereby prevent NH<sub>3</sub>  
25 and NO<sub>x</sub> from being discharged without being purified. Note that the target air-fuel ratio (A/F)<sub>T</sub> is changed from the rich air-fuel ratio to the lean air-fuel ratio gradually with the rate SLOPEL, to thereby suppress the undesired fluctuation of the output torque.

In the embodiment shown in Fig. 29, the target air-fuel ratio (A/F)<sub>T</sub> is made smaller gradually with the rate SLOPER, and is made larger gradually with the rate SLOPEL, as shown in, for example, Fig. 26. However, in  
30 this embodiment, the absolute value SLOPER is made smaller than that of SLOPEL, and thus the fluctuation of the output torque is suppressed, while preventing the NH<sub>3</sub>,  
35



amount from being too small to purify  $\text{NO}_x$ .

Further, in the embodiment shown in Fig. 29, the target air-fuel ratio  $(A/F)_T$  is kept constant at the lean air-fuel ratio  $(A/F)_L$  for a predetermined period, after  
5 the target air-fuel ratio  $(A/F)_T$  is made equal to the lean air-fuel ratio  $(A/F)_L$ , and then is made smaller toward the rich air-fuel ratio  $(A/F)_R$ . The target air-fuel ratio  $(A/F)_T$  is kept constant at the rich air-fuel ratio  $(A/F)_R$  for a predetermined period, after  
10 the target air-fuel ratio  $(A/F)_T$  is made equal to the rich air-fuel ratio  $(A/F)_R$ , and then is made larger toward the lean air-fuel ratio  $(A/F)_L$ . As a result, the changing operation of the target air-fuel ratio  $(A/F)_T$  between the lean and the rich air-fuel ratios per unit  
15 time is made smaller, and thereby the drivability is further enhanced.

In the embodiments shown in Figs. 26 to 29, while the changing rate  $\text{SLOPE}_L$ ,  $\text{SLOPE}_R$  may be set constant regardless the engine operating condition, the rate  
20  $\text{SLOPE}_L$ ,  $\text{SLOPE}_R$  may be set in accordance with the engine operating condition. Fig. 30 shows relationships between the rates  $\text{SLOPE}_L$  and  $\text{SLOPE}_R$  and the engine load  $Q/N$ . As shown in Fig. 30, each rate  $\text{SLOPE}_L$ ,  $\text{SLOPE}_R$  becomes smaller as the engine load  $Q/N$  becomes higher. The rates  
25  $\text{SLOPE}_L$  and  $\text{SLOPE}_R$  are stored in the ROM 22 in advance in the form of a map shown in Fig. 30.

Further, in the embodiments shown in Figs. 26 to 29, the changing rates  $\text{SLOPE}_L$  and  $\text{SLOPE}_R$  are kept constant through one changing process of the target air-fuel ratio  
30  $(A/F)_T$  between the lean and the rich air-fuel ratios. Alternatively, the changing rates  $\text{SLOPE}_L$  and  $\text{SLOPE}_R$  may be changed in one changing process of the target air-fuel ratio  $(A/F)_T$ , in accordance with, for example, the engine operating condition.

35 On the other hand, the ignition timing for each cylinder is changed gradually in accordance with the

change in the target air-fuel ratio  $(A/F)_T$ , when the target air-fuel ratio  $(A/F)_T$  is changed as in the embodiments mentioned above. Namely, in the embodiment shown in Fig. 26, for example, the ignition timing IT is  
5 retarded gradually with a changing rate SR when the target air-fuel ratio  $(A/F)_T$  is made smaller gradually, and is advanced gradually with a changing rate SL when the target air-fuel ratio  $(A/F)_T$  is made larger gradually. The rates SL and SR corresponds to the rates  
10 SLOPEL and SLOPER, respectively. This suppresses the undesired fluctuation in the output torque more effectively. Note that the rates SL and SR may be kept constant, or may be changed in accordance with the engine operating condition.

15 Fig. 31 shows a routine for controlling the ignition timing in the embodiment shown in Fig. 26. This routine is executed by interruption every predetermined crank angle.

Referring to Fig. 31, first, in step 170, it is  
20 judged whether FRICH, which is made zero or 1 in the routine shown in Fig. 10, is made 1. If  $FRICH = 0$ , that is, if the engine has to perform the lean operation, the routine goes to step 171, where the ignition timing IT is increased by SL, namely, is advanced by SL. In the  
25 following step 172, ITL is calculated in accordance with the engine operating condition, for example. In the following step 173, it is judged whether the ignition timing IT is larger than ITL. If  $IT > ITL$ , the routine goes to step 174, where the ignition timing IT is limited  
30 to ITL. Then, the processing cycle is ended.

If  $FRICH = 1$  in step 170, that is, if the engine has to perform the rich operation, the routine goes to step 175, where the ignition timing IT is decreased by SR, namely, is retarded by SR. In the following  
35 step 176, ITR is calculated in accordance with, for example, the engine operation. In the following step 177, it is judged whether the ignition timing IT is

smaller than ITR. If  $IT < ITR$ , the routine goes to step 178, where the ignition timing IT is limited to ITR. Then, the processing cycle is ended.

Fig. 32 shows another embodiment for the engine according to the present invention. In Fig. 32, constituent elements the same as those in Fig. 1 are given the same reference numerals. The engine is provided with an electronic control unit same as shown in Fig. 1, but it is not depicted in Fig. 32.

Referring to Fig. 32, the engine body 1 is provided with a first bank 1a arranged in one side of the crank shaft (not shown), and a second bank 1b arranged in the other side of the crank shaft. The first bank 1a comprises the first, the third, the fifth, and the seventh cylinders #1, #3, #5, and #7 aligned straight, and the second bank 1b comprises the second, the fourth, the sixth, and the eighth cylinders #2, #4, #6, and #8 aligned straight. Connected to the cylinders of the first bank 1a is a common exhaust manifold 7a, and connected to the cylinders of the second bank 1b is a common exhaust manifold 7b. The exhaust manifolds 7a and 7b are connected to the common TW catalyst 8a via corresponding exhaust pipes 80a, 80b. Note that the upstream side air-fuel ratio sensor 29a is arranged in the exhaust passage downstream of the portion meeting the exhaust pipes 80a and 80b, in this embodiment. Alternatively, the upstream side sensor 29a may comprise a pair of sensors, one being arranged in the manifold 7a, and the other being arranged in the manifold 7b.

This engine also performs the lean and the rich engine operations alternately and repeatedly, to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean and rich alternately and repeatedly, as shown in Fig. 5. Namely, the engine performs the rich operation to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a rich, to thereby synthesize

NH<sub>3</sub> and adsorbed NH<sub>3</sub> in the NH<sub>3</sub>-AO catalyst 10a, and performs the lean operation to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean, to thereby desorb NH<sub>3</sub> and  
5 reduce NO<sub>x</sub> by the desorbed NH<sub>3</sub> in the NH<sub>3</sub>-AO catalyst 10a.

In this engine, the lean and the rich operation period may be set on the basis of the cylinder number ratio RATIO, as explained with reference to Figs. 13 to 21. In this case, the ratio RATIO is selected from 1 to  
10 7. In the multi-cylinder engine with 8 or more cylinders, as shown in Fig 32, the ratio RATIO can be set larger such as 5, 6, and 7, and thus the fuel consumption rate is made lower than that in the engine shown in Fig. 1.

15 In the engine shown in Fig. 32, the exhaust stroke is in process, in the order of the first, the eighth, the fourth, the third, the sixth, the fifth, the seventh, and the second cylinders, whenever the crank shaft turns by about 90 degrees. In this case, the beginning of the  
20 exhaust stroke period of a certain cylinder overlaps the end of that of the preceding cylinder, and the end of the exhaust stroke period of that certain cylinder overlaps the beginning of that of the following cylinder. However, when the engine performs the lean and the rich  
25 operations alternately and repeatedly, the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a is made lean and rich alternately and repeatedly. Thus, even though the exhaust stroke period overlaps that of the other cylinder, the exhaust  
30 gas can be purified sufficiently. The other constructions of the exhaust purifying device and the operation thereof are the same as those in the engine shown in Fig. 1, and thus the explanations therefor are omitted.

35 Next, another embodiment for the engine shown in Fig. 32 will be explained.

In this embodiment, the engine 1 is provided with four cylinder groups, that is, a first group having the first and the second cylinders, a second group having the third and the fourth cylinders, a third group having the fifth and the sixth cylinders, a fourth group having the seventh and the eighth cylinders. The exhaust stroke periods of the cylinders in the same cylinder groups are substantially identical to each other, but the exhaust stroke periods of the groups are different from each other. Namely, the exhaust strokes are in process whenever the crank shaft turns by about 90 degrees, in the order of the first, the third, the fourth, and the second cylinder groups.

This engine also performs the lean and the rich engine operations alternately and repeatedly, to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean and rich alternately and repeatedly, as shown in Fig. 5. Namely, the engine performs the rich operation to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a rich, to thereby synthesize  $\text{NH}_3$  and adsorbed  $\text{NH}_3$  in the  $\text{NH}_3$ -AO catalyst 10a, and performs the lean operation to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10a lean, to thereby desorb  $\text{NH}_3$  and reduce  $\text{NO}_x$  by the desorbed  $\text{NH}_3$  on the  $\text{NH}_3$ -AO catalyst 10a.

In this engine, to make the exhaust gas air-fuel ratio of the exhaust gas exhausted from the first cylinder group, for example, equal to the target air-fuel ratio  $(A/F)_T$ , any method may be applied to set the engine air-fuel ratios of the first and the second cylinders #1 and #2. In the embodiment, the engine air-fuel ratios of the first and the second cylinders #1 and #2 are set identical to each other and are made equal to the target air-fuel ratio  $(A/F)_T$ . However, the important point is that making the exhaust gas air-fuel ratio of the exhaust

gas flowing into the catalysts 8a and 10a equal to the target air-fuel ratio (A/F)<sub>T</sub>, and making both of the engine air-fuel ratios of the first and the second cylinders equal to the target air-fuel ratio (A/F)<sub>T</sub> is unnecessary. The above explanation may be applied to the other cylinder groups, and thus particular explanations therefor are omitted.

In this engine, the lean and the rich operation period may also be set on the basis of the cylinder number ratio *RATIO*, as explained with reference to Figs. 13 to 21. In this case, the ratio *RATIO* may be considered as a ratio of the number of the cylinder groups performing the lean operation to the number of the cylinder groups performing the rich operation, in one cycle. Further, note that each cylinder group may have a single cylinder. The other constructions of the exhaust purifying device and the operation thereof are the same as those in the engine shown in Fig. 1, and thus the explanations therefor are omitted.

Next, another embodiment for the engine shown in Fig. 33 will be explained. In Fig. 33, constituent elements the same as those in Fig. 1 are given the same reference numerals.

Referring to Fig. 33, the exhaust gas purifying catalyst 10 is housed in the catalytic converter 9 in which the TW catalyst 8a is housed. Especially, the exhaust gas purifying catalyst 10 is carried on the substrate carrying the TW catalyst 8a, and is arranged downstream of the TW catalyst 8a, in series, as shown in Fig. 33. Additionally, the NH<sub>3</sub> purifying catalyst 12 is arranged downstream of the exhaust gas purifying catalyst 10, as in the engine shown in Fig. 1.

In the engine shown in Fig. 33, the exhaust gas purifying catalyst 10 consists of a NO<sub>x</sub> occluding and reducing catalyst 10b, which is simply expressed as a NO<sub>x</sub>-OR catalyst. The NO<sub>x</sub>-OR catalyst 10b comprises at

least one substance selected from alkali metals such as potassium K, sodium Na, lithium Li, and cesium Cs, alkali earth metals such as barium Ba and calcium Ca, rare earth metals such as lanthanum La and yttrium Y, and transition  
5 metals such as iron Fe and copper Cu, and of precious metals such as palladium Pd, platinum Pt, and rhodium Rh, which are carried on alumina as a carrier. The NO<sub>x</sub>-OR catalyst 10b performs the NO<sub>x</sub> occluding and releasing  
10 function in which it occludes NO<sub>x</sub> therein when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, and releases the occluded NO<sub>x</sub> therefrom when the oxygen concentration in the inflowing exhaust gas becomes lower.

When the NO<sub>x</sub>-OR catalyst 10b is disposed in the  
15 exhaust passage of the engine, the NO<sub>x</sub>-OR catalyst 10b actually performs the NO<sub>x</sub> occluding and releasing function, but the function is unclear. However, it can be considered that the function is performed according to the mechanism as shown in Fig. 34. This mechanism will  
20 be explained by using as an example a case where platinum Pt and barium Ba are carried on the carrier, but a similar mechanism is obtained even if another precious metal, alkali metal, alkali earth metal, or rare earth metal is used.

25 Namely, when the exhaust gas air-fuel ratio of the inflowing exhaust gas becomes lean, that is, when the oxygen concentration in the inflowing exhaust gas increases, the oxygen O<sub>2</sub> is deposited on the surface of platinum Pt in the form of O<sub>2</sub> or O<sup>2-</sup>, as shown in  
30 Fig. 34A. On the other hand, NO in the inflowing exhaust gas reacts with the O<sub>2</sub> or O<sup>2-</sup> on the surface of the platinum Pt and becomes NO<sub>2</sub> (2NO + O<sub>2</sub> → 2NO<sub>2</sub>). Subsequently, a part of the produced NO<sub>2</sub> is oxidized on the platinum Pt and is occluded into the NO<sub>x</sub>-OR  
35 catalyst 10b. While bonding with barium oxide BaO, it is

diffused in the catalyst 10b in the form of nitric acid ions  $\text{NO}_3^-$ , as shown in Fig. 34A. In this way,  $\text{NO}_x$  is occluded in the  $\text{NO}_x$ -OR catalyst 10b.

Contrarily, when the oxygen concentration in the inflowing exhaust gas becomes lower and the production of  $\text{NO}_2$  is lowered, the reaction proceeds in an inverse direction ( $\text{NO}_3^- \rightarrow \text{NO}_2$ ), and thus nitric acid ions  $\text{NO}_3^-$  in the  $\text{NO}_x$ -OR catalyst 10b is released in the form of  $\text{NO}_2$  from the  $\text{NO}_x$ -OR catalyst 10b, as shown in Fig. 34B.

Namely, when the oxygen concentration in the inflowing exhaust gas is lowered, that is, when the exhaust gas air-fuel ratio of the inflowing exhaust gas is changed lean to rich,  $\text{NO}_x$  is released from the  $\text{NO}_x$ -OR catalyst 10b. At this time, if the reducing agent, such as  $\text{NH}_3$ , exists in the  $\text{NO}_x$ -OR catalyst 10b,  $\text{NO}_x$  is reduced and purified by the agent. Note that, when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich, hydrocarbon HC, carbon monoxide CO, or hydrogen  $\text{H}_2$  may pass through the TW catalyst 8a and may flow into the  $\text{NO}_x$ -OR catalyst 10b. It is considered that the HC, CO, etc. act as the reducing agent, as well as  $\text{NH}_3$ , and reduce a part of  $\text{NO}_x$  on the  $\text{NO}_x$ -OR catalyst 10b.

However, the reducing ability of  $\text{NH}_3$  is higher than those of HC, CO, etc., and thus  $\text{NO}_x$  can be reliably purified by using  $\text{NH}_3$  as the reducing agent.

This engine also performs the lean and the rich engine operations alternately and repeatedly, to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10b lean and rich alternately and repeatedly, as shown in Fig. 38B. When the engine performs the lean operation to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10b lean,  $\text{NO}_x$  in the exhaust gas passes through the TW catalyst 8a, and then flows into the  $\text{NO}_x$ -OR catalyst 10b, as shown in Fig. 35B. At



this time, the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, and thus  $\text{NO}_x$  in the inflowing exhaust gas is occluded in the  $\text{NO}_x$ -OR catalyst 10b.

5           On the other hand, when the engine performs the rich operation to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10b rich, a part of the  $\text{NO}_x$  is converted to  $\text{NH}_3$  on the TW catalyst 8a, as shown in Fig. 35A. The  $\text{NH}_3$  then flows  
10       into the  $\text{NO}_x$ -OR catalyst 10b. At this time, the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich, and thus the occluded  $\text{NO}_x$  is released from the  $\text{NO}_x$ -OR catalyst 10b. The released  $\text{NO}_x$  is reduced by the  $\text{NH}_3$  in the inflowing exhaust gas, and is thus purified. Note  
15       that, even if the  $\text{NH}_3$  amount inflowing the  $\text{NO}_x$ -OR catalyst 10b exceeds an amount required for purifying the released  $\text{NO}_x$ , the excess  $\text{NH}_3$  flows into the  $\text{NH}_3$  purifying catalyst 12, and is purified there. This prevents  $\text{NH}_3$  from being emitted to the ambient air. Further, the lean  
20       and the rich air-fuel ratio (A/F)L and (A/F)R are also set to 25.0 and 13.8, respectively, in this engine.

Next, the method for controlling the lean and the rich operation periods in the engine shown in Fig. 33 will be explained.

25           It is desirable that the lean operation period  $\text{TL}$  is made longer, as in the engine shown in Fig. 1, but the  $\text{NO}_x$ -OR catalyst 10b will saturate with  $\text{NO}_x$  if the lean operation is made too long. On the other hand, if the rich operation is made too short, the target air-fuel  
30       ratio (A/F)T has to be changed between the lean and the rich air-fuel ratios frequently. Thus, in this embodiment, the  $\text{NO}_x$  amount occluded in the  $\text{NO}_x$ -OR catalyst 10b is obtained, and the engine performs the rich operation when the occluded  $\text{NO}_x$  amount exceeds a  
35       predetermined maximum amount in the lean operation, and

performs the lean operation when the occluded  $\text{NO}_x$  amount falls below a predetermined minimum amount in the rich operation.

It is difficult to directly find the occluded  $\text{NO}_x$  amount in the  $\text{NO}_x$ -OR catalyst 10b. Therefore, in this embodiment, the occluded  $\text{NO}_x$  amount is estimated on the basis of the  $\text{NO}_x$  amount flowing into the  $\text{NO}_x$ -OR catalyst 10b, that is, the  $\text{NO}_x$  amount exhausted from the engine. Namely, the exhausted  $\text{NO}_x$  amount per unit time  $Q(\text{NO}_x)$  is calculated using the map shown in Fig. 6.

Fig. 36A illustrates the  $\text{NO}_x$  amount  $D(\text{NO}_x)$  released from the  $\text{NO}_x$ -OR catalyst 10b per unit time, obtained by experiments. In Fig. 36A, the solid curve shows the case where the temperature of the  $\text{NO}_x$ -OR catalyst 10b is high, and the broken curve shows the case where the temperature of the  $\text{NO}_x$ -OR catalyst 10b is low. Further, in Fig. 36A, TIME represents a time starting from when the rich operation starts, that is, when the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a and 10b is changed from the lean air-fuel ratio  $(A/F)_L$  to the rich air-fuel ratio  $(A/F)_R$ . The decomposition rate of  $\text{NO}_x$  in the  $\text{NO}_x$ -OR catalyst 10b becomes higher as the temperature of the catalyst 10b becomes higher. Thus, when the temperature of the  $\text{NO}_x$ -OR catalyst 10b, that is, the temperature of the exhaust gas flowing into the catalyst 10b TNC, is high, as shown by the solid line in Fig. 36A, a large amount of  $\text{NO}_x$  is released from the  $\text{NO}_x$ -OR catalyst 10b in a short time, while when TNC is low as shown by the broken line in Fig. 36A, a small amount of  $\text{NO}_x$  is released. In other words, the released  $\text{NO}_x$  amount per unit time  $D(\text{NO}_x)$  becomes larger as the exhaust gas temperature TNC becomes higher. The released  $\text{NO}_x$  amount  $D(\text{NO}_x)$  is stored in the ROM 22 in advance in the form of a map as shown in Fig. 36B.

While the exhaust gas temperature TNC may be

detected by using a temperature sensor arranged in the exhaust passage, TNC is estimated on the basis of the engine load Q/N and the engine speed N, in this embodiment. That is, TNC is obtained in advance by experiment and is stored in the ROM 22 in advance in the form of a map as shown in Fig. 37.

Next, the method for controlling the operation period for the engine shown in Fig. 33 will be explained in more detail, with reference to Figs. 38A and 38B. The routine shown in Fig. 38A is executed by interruption every predetermined crank angle.

Referring to Fig. 38A, first, in step 80, it is judged whether FRICH is made 1. FRICH is made 1 when the rich operation is to be performed, and is made zero when the lean operation is to be performed. If FRICH is 1, that is, if the rich operation is to be performed, the routine goes to step 81, where the exhaust gas temperature TNC is calculated using the map shown in Fig. 37. In the following step 82, D(NO<sub>x</sub>) is calculated using the map shown in Fig. 36B. In the following step 83, the NO<sub>x</sub> amount S(NO<sub>x</sub>) occluded in the NO<sub>x</sub>-OR catalyst 10b is calculated using the following equation:

$$S(\text{NO}_x) = S(\text{NO}_x) - D(\text{NO}_x) \cdot \text{DELTA}d$$

where DELTAd is a time interval from the last processing cycle until the present processing cycle. In the following step 84, it is judged whether the occluded NO<sub>x</sub> amount S(NO<sub>x</sub>) is smaller than the minimum amount MIN(NO<sub>x</sub>). If  $S(\text{NO}_x) \geq \text{MIN}(\text{NO}_x)$ , the processing cycle is ended. Namely, if  $S(\text{NO}_x) \geq \text{MIN}(\text{NO}_x)$ , it is judged that the occluded NO<sub>x</sub> amount S(NO<sub>x</sub>) is still large, and thus the rich operation is continued.

If  $S(\text{NO}_x) < \text{MIN}(\text{NO}_x)$ , the routine goes to step 85, where FRICH is made zero and the processing cycle is ended. Namely, if  $S(\text{NO}_x) < \text{MIN}(\text{NO}_x)$ , it is judged that the NO<sub>x</sub>-OR catalyst 10b cannot release NO<sub>x</sub> sufficient for

the  $\text{NH}_3$  flowing therein, and thus the rich operation is stopped and the lean engine operation starts (as at the time a, c, e, or g shown in Fig. 38B).

Contrarily, if  $\text{FRICH} = 0$  in step 80, that is, if the lean operation is to be performed, the routine goes to step 86, where the exhausted  $\text{NO}_x$  amount  $Q(\text{NO}_x)$  is calculated using the map shown in Fig. 6B. In the following step 87, the occluded  $\text{NO}_x$  amount  $S(\text{NO}_x)$  is calculated using the following equation:

$$S(\text{NO}_x) = S(\text{NO}_x) + Q(\text{NO}_x) \cdot \text{DELTAa}$$

where  $\text{DELTAa}$  is a time interval from the last processing cycle until the present processing cycle. In the following step 88, it is judged whether the occluded  $\text{NO}_x$  amount  $S(\text{NO}_x)$  is larger than the maximum amount  $\text{MAX}(\text{NO}_x)$ , which is determined in accordance with the occluding capacity of the catalyst 10b. If  $S(\text{NO}_x) \leq \text{MAX}(\text{NO}_x)$ , the processing cycle is ended. Namely, if  $S(\text{NO}_x) \leq \text{MAX}(\text{NO}_x)$ , the occluded  $\text{NO}_x$  amount is judged to be small, and thus the lean operation is continuously performed.

If  $S(\text{NO}_x) > \text{MAX}(\text{NO}_x)$ , the routine goes to step 89, where  $\text{FRICH}$  is made 1, and then the processing cycle is ended. Namely, if  $S(\text{NO}_x) > \text{MAX}(\text{NO}_x)$ , the occluded  $\text{NO}_x$  amount is considerably large, and the lean operation is stopped and the rich operation starts (as at the time b, d, or f shown in Fig. 38B).

Also, in this embodiment, the exhaust gas can be purified sufficiently without providing a plurality of the exhaust passages. Accordingly, the structure of the exhaust passage is kept small and simple. The other constructions of the exhaust purifying device and the operation thereof are the same as those in the engine shown in Fig. 1, and thus the explanations therefor are omitted.

Next, a further embodiment will be explained with reference to Fig. 39. In Fig. 39, constituent elements

the same as those in Fig. 1 are given the same reference numerals.

Referring to Fig. 39, the exhaust gas purifying catalyst 10 comprises both of the  $\text{NH}_3$ -AO catalyst 10a and the  $\text{NO}_x$ -OR catalyst 10b. The  $\text{NO}_x$ -OR catalyst 10b is carried on the carrier common to the TW catalyst 8a, and the  $\text{NH}_3$ -AO catalyst 10a is arranged in the muffler 11 downstream of the  $\text{NO}_x$ -OR catalyst 10b. Further, the  $\text{NH}_3$  purifying catalyst 12 is arranged downstream of the  $\text{NH}_3$ -AO catalyst 10a.

In this engine again, the target air-fuel ratio (A/F)<sub>T</sub> of the cylinders is made equal to the lean and the rich air-fuel ratios (A/F)<sub>L</sub> and (A/F)<sub>R</sub> alternately and repeatedly, to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a lean and rich alternately and repeatedly. In this embodiment, the purification of the exhaust gas is performed mainly by the  $\text{NO}_x$ -OR catalyst 10b, arranged on the upstream side, and the  $\text{NH}_3$ -AO catalyst 10a is auxiliary. Namely, when the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a is made lean, as shown in Fig. 40B,  $\text{NO}_x$  exhausted from the engine passes through the TW catalyst 8a, and then flows into the  $\text{NO}_x$ -OR catalyst 10b. At this time, the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, and thus  $\text{NO}_x$  is occluded in the  $\text{NO}_x$ -OR catalyst 10b. Even if the  $\text{NO}_x$  passes through the  $\text{NO}_x$ -OR catalyst 10b without being occluded, the  $\text{NO}_x$  is purified in the following  $\text{NH}_3$ -AO catalyst 10a. Namely, at this time, the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean and thus  $\text{NH}_3$  is desorbed therefrom, and thereby this  $\text{NH}_3$  reduces  $\text{NO}_x$ . Note that, when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean,  $\text{NH}_3$  is desorbed from the  $\text{NH}_3$ -AO catalyst 10a regardless the  $\text{NO}_x$  amount flowing therein. However, the

excess  $\text{NH}_3$  is purified in the following catalyst 12. Accordingly,  $\text{NO}_x$  and  $\text{NH}_3$  both are prevented from being emitted to the ambient air.

5 When the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a is made rich, as shown in Fig. 40A,  $\text{NO}_x$  exhausted from the engine flows into the TW catalyst 8a, and a part thereof is converted to  $\text{NH}_3$ . The  $\text{NH}_3$  then flows into the  $\text{NO}_x$ -OR catalyst 10b. At this time, the exhaust gas air-fuel  
10 ratio of the inflowing exhaust gas is rich,  $\text{NO}_x$  is released from the  $\text{NO}_x$ -OR catalyst 10b. The  $\text{NO}_x$  is reduced and purified by the inflowing  $\text{NH}_3$ . Even if  $\text{NH}_3$  passes through the  $\text{NO}_x$ -OR catalyst 10b without reducing  $\text{NO}_x$ , the  $\text{NH}_3$  is adsorbed in the  $\text{NH}_3$ -AO catalyst 10a.  
15 Further, even if  $\text{NH}_3$  passes through the  $\text{NH}_3$ -AO catalyst 10a without being adsorbed therein, the  $\text{NH}_3$  is purified in the catalyst 12. Accordingly,  $\text{NO}_x$  and  $\text{NH}_3$  both are purified sufficiently.

In this embodiment, the lean and the rich operation periods TL and TR are set in accordance with the occluded  
20  $\text{NO}_x$  amount in the  $\text{NO}_x$ -OR catalyst 10b, as in the engine shown in Fig. 33. Namely, the lean operation is stopped and the rich operation starts when the occluded  $\text{NO}_x$  amount exceeds over the maximum amount, and the rich  
25 operation is stopped and the lean operation starts when the occluded  $\text{NO}_x$  amount falls below the minimum amount. However, if the occluded  $\text{NO}_x$  amount exceeds the maximum amount and the catalyst 10b saturates,  $\text{NO}_x$  passing  
30 through the catalyst 10b then flows into the  $\text{NH}_3$ -AO catalyst 10a and is reduced by  $\text{NH}_3$  desorbed therefrom. Accordingly, precise control of the operation period is unnecessary for purifying  $\text{NO}_x$  sufficiently.

Alternatively, the lean and the rich operation periods TL and TR may be set in accordance with the  $\text{NH}_3$

amount adsorbed in the  $\text{NH}_3$ -AO catalyst 10a, as in the engine shown in Fig. 1. Further alternatively, the lean and the rich operation periods TL and TR may be set in the manner that the lean operation is stopped and the rich operation starts when the occluded  $\text{NO}_x$  amount in the  $\text{NO}_x$ -OR catalyst 10b exceeds the maximum amount therefor, and the rich operation is stopped and the lean operation starts when the adsorbed  $\text{NH}_3$  amount in the  $\text{NH}_3$ -AO catalyst 10a exceeds the maximum amount therefor.

Further alternatively, the rich operation may start when the adsorbed  $\text{NH}_3$  amount in the  $\text{NH}_3$ -AO catalyst 10a falls below the minimum amount therefor during the lean operation, and lean operation may start when the occluded  $\text{NO}_x$  amount in the  $\text{NO}_x$ -OR catalyst 10b falls below the minimum amount therefor during the rich operation. In this alternative, setting the minimum amounts for the catalysts 10a and 10b relatively large results in that  $\text{NH}_3$  is always adsorbed in the  $\text{NH}_3$ -AO catalyst 10a and  $\text{NO}_x$  is always occluded in the  $\text{NO}_x$ -OR catalyst 10b. Thus, even though the actual engine air-fuel ratio deviates from the target air-fuel ratio  $(A/F)_T$  due to the engine transient operation, the exhaust gas is purified sufficiently by at least one of the catalysts 10a and 10b. Accordingly, the exhaust gas is purified regardless the engine operation condition.

In this way, the engine shown in Fig. 39 also purifies the exhaust gas with a single exhaust passage.

In the embodiment shown in Fig. 39, the  $\text{NO}_x$ -OR catalyst 10b is arranged on the upstream side, and the  $\text{NH}_3$ -AO catalyst 10a is arranged on the downstream side, considering the endurance temperatures of the catalysts 10a and 10b. Alternatively, the  $\text{NH}_3$ -AO catalyst 10a may be arranged on the upstream side, and the  $\text{NO}_x$ -OR catalyst 10b is arranged on the downstream side. In this alternative, setting the lean and the rich

operation periods in accordance with the adsorbed  $\text{NH}_3$  amount in the  $\text{NH}_3$ -AO catalyst 10a makes the controllability easier. Further alternatively, the catalysts 10a and 10b may be arranged in parallel. The other constructions of the exhaust purifying device and the operation thereof are the same as those in the engine shown in Fig. 1, and thus the explanations therefor are omitted.

Figs. 41A and 41B illustrate another embodiment for the arrangement of the exhaust gas purifying catalyst 10.

Referring to Figs. 41A and 41B, the  $\text{NH}_3$ -AO catalyst 10a and the  $\text{NO}_x$ -OR catalyst 10b are carried on a common substrate, while they are carried on the individual substrates in the embodiment shown in Fig. 39. Namely, in the embodiment shown in Fig. 41A, the catalysts 10a and 10b are laminated to each other and carried on a common substrate 110. As shown in Fig. 41A, a layer comprised of the  $\text{NH}_3$ -AO catalyst 10a is first formed over the surface of the substrate 110 having a honeycomb structure, and then a layer comprised of the  $\text{NO}_x$ -OR catalyst 10b is formed over the  $\text{NH}_3$ -AO catalyst 10a. As mentioned above, the endurance temperature of the  $\text{NO}_x$ -OR catalyst 10b is higher than that of the  $\text{NH}_3$ -AO catalyst 10a. Therefore, covering the  $\text{NH}_3$ -AO catalyst 10a by the  $\text{NO}_x$ -OR catalyst 10b prevents the direct contact of the exhaust gas with the  $\text{NH}_3$ -AO catalyst 10a. As a result, good purification of the exhaust gas is ensured, while ensuring the endurance of the  $\text{NH}_3$ -AO catalyst 10a.

On the other hand, in the embodiment shown in Fig. 41B a layer 10c is carried on the substrate 110. The layer includes the catalysts 10a and 10b in a mixed form. In this case, for example, the  $\text{NH}_3$ -AO catalysts 10a are comprised of zeolite carrying the metal thereon by the ion changing process, and the  $\text{NO}_x$ -OR



catalyst 10b is comprised of alumina carrying the precious metal and the alkali metal or alkali earth metal or the like. These catalysts 10a and 10b are mixed and then applied over the surface of the substrate 110.

5        This way of carrying the catalysts 10a and 10b makes the structure of the exhaust gas purifying device simpler.

10        Next, another embodiment will be explained with reference to Fig. 42. In Fig. 42, constituent elements the same as those in Fig. 1 are given the same reference numerals. Also, in Fig. 42, the exhaust gas purifying catalyst 10 comprises both the  $\text{NH}_3$ -AO catalyst 10a and the  $\text{NO}_x$ -OR catalyst 10b, but one of them may be omitted.

15        Referring to Fig. 42, there is provided a making rich device 120 for making the exhaust gas air-fuel ratio of the exhaust gas, flowing into the catalysts 8a, 10a, and 10b, rich. In this embodiment, the device 120 comprises an auxiliary internal combustion engine 120a, of which a crank shaft is different from that of the  
20        engine 1. Arranged in an intake duct 124 of the auxiliary engine 120a is a fuel injector 125 for feeding fuel such as gasoline to the auxiliary engine 120a. In the intake duct 124 upstream of the injector 125, a throttle valve 126 is also arranged. On the other hand,  
25        an exhaust pipe 127 of the auxiliary engine 1 is connected to an interconnecting pipe 129 connecting both of the exhaust manifold 7 and exhaust pipe 127 to the catalytic converter 9 in which the TW catalyst 8a is housed. Thus, the exhaust gas flowing into, in turn, the  
30        catalysts 8a, 10b, 10a, and 12 is a mixture of the exhaust gas from the engine 1 and that from the auxiliary engine 120a. Note that, while the auxiliary engine 120a shown in Fig. 42 is constructed as an spark-ignition type engine having a single cylinder, the auxiliary  
35        engine 120a may be constructed as a multi-cylinder engine, or a diesel engine.

Mounted in the intake duct 124 is a pressure sensor 137 generating an output voltage proportional to a pressure in the intake duct 124. The output voltage of the sensor 137 is input via an AD converter 138 to the input port 25. The intake air amount AQ of the auxiliary engine 120a is calculated in the CPU 24 on the basis of the output signals from the AD converter 138. Further, mounted in the collecting portion of the exhaust manifold 7 is an upstream side air-fuel ratio sensor 29c generating an output voltage proportional to an exhaust gas air-fuel ratio of the exhaust gas flowing through the collecting portion of the exhaust manifold 7. The output voltage of the sensor 29c is input via an AD converter 30c to the input port 25. The air-fuel ratio sensor 29a is mounted in the interconnecting pipe 129 downstream on the meeting point where the exhaust gases from the exhaust manifold 7 and the exhaust pipe 127 meet with each other. Thus, the sensor 29a generates an output voltage proportional to the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a. Further, connected to the input port 25 is a crank angle sensor 131 generating an output pulse whenever the crank shaft of the auxiliary engine 120a turns by, for example, 30 degrees. The CPU 24 calculates the engine speed AN of the auxiliary engine 120a in accordance with the pulse. Further, arranged in the interconnecting pipe 129 downstream of the meeting point mentioned above is a temperature sensor 140 generating an output voltage proportional to the temperature of the exhaust gas flowing into the catalysts 8a, 10b, and 10a, which represents the temperature of the catalysts 8a and 10b. The output port 26 is connected to the fuel injector 125 via a corresponding drive circuit 32.

The output torque of the engine 1 is used for driving the automobile, for example. Contrarily, the output torque of the auxiliary engine 120a is used for driving an auxiliary device 132, such as a cooling device

for an insulated van, a mixer for a concrete mixer truck,  
an air-conditioner for a bus, and an electric generator  
for generating the electric power for the electrical  
motor of the so-called hybrid type vehicle which is  
5 driven by the engine and the electrical motor. The  
throttle valve 126 of the auxiliary engine 120a is  
controlled in accordance with the required output torque  
of the auxiliary engine 120a. Alternatively, the  
auxiliary device 132 may be an auxiliary machinery of the  
10 engine 1 such as a cooling water pump, an oil pump, and  
an alternator.

In this embodiment, basically, the engine 1 performs  
the lean operation continuously with the lean air-fuel  
ratio (A/F)<sub>L</sub> such as 25.0, as shown in Fig. 43A by a  
15 broken line. This results in further decreasing the fuel  
consumption rate. Note that, when the engine 1 is  
quickly accelerated, the engine 1 may perform the  
stoichiometric operation in which the engine air-fuel  
ratio is made equal to the stoichiometric air-fuel ratio,  
20 to thereby ensure the larger output torque.

On the other hand, in this embodiment, the exhaust  
gas air-fuel ratio of the exhaust gas flowing into the  
catalysts 8a, 10b, and 10a is made lean and rich  
alternately and repeatedly, in particular, is made equal  
25 to the lean and the rich air-fuel ratios (A/F)<sub>L</sub> and  
(A/F)<sub>R</sub> alternately and repeatedly, as shown in Fig. 43A  
by the solid line.

To make the exhaust gas air-fuel ratio of the  
exhaust gas flowing into the catalysts 8a, 10b, and 10a  
30 lean, the auxiliary engine 120a performs a lean  
operation. In particular, to make the exhaust gas  
air-fuel ratio of the exhaust gas flowing into the  
catalysts 8a, 10b, and 10a equal to the lean air-fuel  
ratio (A/F)<sub>L</sub>, the exhaust gas air-fuel ratio of the  
35 exhaust gas from the auxiliary engine 120a, that is, the  
engine air-fuel ratio of the auxiliary engine 120a is  
made equal to the lean air-fuel ratio (A/F)<sub>AL</sub>. In this

embodiment, the exhaust gas air-fuel ratio of the exhaust gas from the engine 1 is made equal to  $(A/F)L$ , and thus the lean air-fuel ratio  $(A/F)AL$  is identical to  $(A/F)L$ . In other word, in this case, the target air-fuel ratio  $(A/F)AT$  of the auxiliary engine 120a is made  $(A/F)L$ , as shown in Fig. 43A by the two-dot chain line.

To make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a rich, the auxiliary engine 120a performs the rich operation. In particular, to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to a rich air-fuel ratio  $(A/F)R$  such as 13.8, the engine air-fuel ratio of the auxiliary engine 120a is made equal to the rich air-fuel ratio  $(A/F)AR$ , which is smaller or richer than the rich air-fuel ratio  $(A/F)R$ . In other word, in this case, the target air-fuel ratio  $(A/F)AT$  of the auxiliary engine 120a is made  $(A/F)AR$ , as shown in Fig. 43A by the two-dot chain line. In this way, the auxiliary engine 120a performs the lean and rich operation alternately and repeatedly, while the engine 1 performs the lean operation continuously.

Namely, the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a is kept lean when the auxiliary engine 120a performs the lean operation, as shown in Fig. 43B by the solid line, and is changed to rich when the auxiliary engine 120a performs the rich operation, as shown in Fig. 43B by the broken line.

The engine air-fuel ratio of the engine 1 is made equal to the lean air-fuel ratio  $(A/F)$  on the basis of the output signals from the air-fuel ratio sensor 29c. The engine air-fuel ratio of the auxiliary engine 120a is controlled to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to the lean and the rich air-fuel ratios  $(A/F)L$  and  $(A/F)R$  on the basis of the output signals from the

air-fuel ratio sensor 29a.

In this embodiment, the lean operation period, which is a period during which the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalyst 8a, 10b, and 10a is made lean, and the rich operation period, which is a period during which the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a is made rich, are controlled in accordance with at least one of the  $\text{NH}_3$  amount  $S(\text{NH}_3)$  adsorbed in the  $\text{NH}_3$ -AO catalyst 10a, and the  $\text{NO}_x$  amount  $S(\text{NO}_x)$  occluded in the  $\text{NO}_x$ -OR catalyst 10b. Namely, the lean and the rich operation of the auxiliary engine 120a is controlled in accordance with at least one of  $S(\text{NH}_3)$  and  $S(\text{NO}_x)$ . Namely, for example, the engine operation of the auxiliary engine 120a is changed from the lean operation to the rich operation when the adsorbed  $\text{NH}_3$  amount exceeds the maximum amount therefor, and is changed from the rich operation to the lean operation when the adsorbed  $\text{NH}_3$  amount falls below the minimum amount therefor.

The occluded  $\text{NO}_x$  amount  $S(\text{NO}_x)$  is estimated on the basis of the  $\text{NO}_x$  amount flowing into the  $\text{NO}_x$ -OR catalyst 10b, that is, the sum of the  $\text{NO}_x$  amounts exhausted from the engines 1 and 120a. The adsorbed  $\text{NH}_3$  amount  $S(\text{NH}_3)$  is estimated on the basis of the synthesized  $\text{NH}_3$  amount in the catalyst 8a, which is estimated on the basis of the  $\text{NO}_x$  amounts exhausted from the engines 1 and 120a, and the released  $\text{NO}_x$  amount from the  $\text{NO}_x$ -OR catalyst 10b. Note that the temperatures TTC and TNC representing the temperatures of the catalysts 8a and 10b are detected by the sensor 140, and the temperature TAC representing the temperature of the catalyst 10a is estimated on the basis of the output signals from the sensor 140.

Fig. 44 illustrates the routine for calculating the

fuel injection time TAU for the engine 1.

Referring to Fig. 44, first, in step 180, the basic fuel injection time TB is calculated using the following equation:

5 
$$TB = (Q / N) \cdot K$$

In the following step 181, the feedback correction coefficient FAF is calculated, on the basis of the output signals from the sensor 29c. In the following step 182, the lean air-fuel ratio (A/F)L is calculated. In the following step 183, the lean air-fuel ratio (A/F)L is memorized as the target air-fuel ratio (A/F)T. In the following step 184, the fuel injection time TAU is calculated using the following equation:

15 
$$TAU = TB \cdot ((A/F)S / (A/F)T) \cdot FAF$$
  
Each fuel injector 5 injects the fuel for the fuel injection time TAU.

Fig. 45 illustrates the routine for calculating the fuel injection time ATAU for the auxiliary engine 120a.

Referring to Fig. 45, first, in step 190, the basic fuel injection time ATB is calculated using the following equation, on the basis of the engine load AQ/AN and the engine speed AN:

20 
$$ATB = (AQ / AN) \cdot K$$
  
In the following step 191, the feedback correction coefficient AFAP is calculated on the basis of the output signals from the sensor 29a. The feedback correction coefficient AFAP is for controlling the engine air-fuel ratio of the auxiliary engine 120a to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to the lean or the rich air-fuel ratio (A/F)L, (A/F)R. In the following step 192, it is judged whether FRICH, which is controlled in the routine shown in Fig. 10, is made 1. If FRICH = 1, that is, if the rich operation is to be performed, the routine goes to step 193, where the rich air-fuel ratio (A/F)AR is calculated. In the following step 194, the rich air-fuel ratio (A/F)AR is memorized as

the target air-fuel ratio (A/F)AT. Next, the routine goes to step 197.

Contrarily, if FRICH is zero in step 192, that is, if the lean operation is to be performed, the routine goes to step 195, where the lean air-fuel ratio (A/F)AL is calculated. In the following step 196, the lean air-fuel ratio (A/F)AL is memorized as the target air-fuel ratio (A/F)AT. Next, the routine goes to step 197.

In step 197, the fuel injection time ATAU is calculated using the following equation:

$$\text{ATAU} = \text{ATB} \cdot ((\text{A/F})\text{S} / (\text{A/F})\text{AT}) \cdot \text{AFAP}$$

The fuel injector 125 injects the fuel for the fuel injection time ATAU.

In the embodiment shown in Fig. 42, the engine 1 performs the lean operation continuously and the auxiliary engine 120a performs the lean and the rich operation alternately and repeatedly. In this case, the crank shafts thereof are different to each other, and thus the drivability is prevented from being deteriorated, while ensuring the good purification of the exhaust gas. Further, the auxiliary engine 120a provides an additional output torque. Furthermore, if the engine 1 is originally provided with the auxiliary engine 120a, there is no need to newly provide the making-rich device 120, and thereby the structure of the exhaust gas purifying device is made simpler. The other constructions of the exhaust purifying device and the operation thereof are the same as those in the engine shown in Fig. 1, and thus the explanations therefor are omitted.

Fig. 46 illustrates still further another embodiment. In Fig. 46, constituent elements the same as those in Figs. 1 and 42 are given the same reference numerals.

In this embodiment, the making-rich device 120 comprises a burner 120b, of which an air-fuel ratio is

controllable. The exhaust gas of the burner 120b flows into the TW catalyst 8a via the pipes 127 and 129, and is mixed with the exhaust gas from the engine 1.

5       Next, the exhaust gas purifying method in this embodiment will be explained with respect to Fig. 47. The exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a is made the lean and the rich air-fuel ratios  $(A/F)_L$  and  $(A/F)_R$ , alternately and repeatedly, as in the preceding embodiments.

10       However, in this embodiment, the burner 120b is stopped and the engine 1 performs the lean operation with the lean air-fuel ratio  $(A/F)_L$ , to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to  $(A/F)_L$ . The

15       burner 120b performs the rich operation with the rich air-fuel ratio  $(A/F)_R$  and the engine 1 performs the lean operation with the lean air-fuel ratio  $(A/F)_L$ , to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to

20        $(A/F)_R$ . Accordingly, the burner 120b is operated and stopped alternately and repeatedly.

      Fuel for the burner 120b may be hydrocarbon such as gasoline, isooctane, hexane, heptane, gas oil, and kerosene or a hydrocarbon which can be stored in a liquid

25       state, such as butane or propane. However, if fuel same as that for the engine 1 is used for the burner 120b, there is no need for providing an additional fuel tank, and thus gasoline is used in this embodiment.

      While the burner 120b is connected to the catalytic

30       converter 9 via the pipes 127 and 129, in this embodiment, it may be provided integrally with the converter 9 or the catalyst 8a. Further, the burner 120b may be continuously operated and perform the lean operation with the lean air-fuel ratio such as  $(A/F)_L$

35       when making the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a lean. The other constructions of the exhaust purifying device



and the operation thereof are the same as those in the engine shown in Fig. 42, and thus the explanations therefor are omitted.

Fig. 48 illustrates still further another embodiment. In Fig. 48, constituent elements the same as those in Figs. 1 and 42 are given the same reference numerals.

In this embodiment, the engine 1 is constructed as a diesel engine, while the spark-ignition type engine may be adopted. Referring to Fig. 48, each fuel injector 5 injects fuel into the corresponding combustion chamber of the cylinder directly. Also, an air-flow meter 27a is arranged in the intake duct 4. The air-flow meter 27a generates an output voltage proportional to the intake air amount, and the output voltage thereof is input via an AD converter 28a to the input port 25.

As shown in Fig. 48, the making-rich device 120 comprises a reducing agent injector 120c arranged in the outlet of the exhaust manifold 7 for adding a reducing agent into the exhaust gas. The reducing agent may be hydrocarbon such as gasoline, isooctane, hexane, heptane, gas oil, and kerosene or a hydrocarbon which can be stored in a liquid state, such as butane or propane, but is preferable to be the same as that for the engine 1.

The engine 1 performs the lean operation continuously. If a diesel engine performs the rich operation, the engine exhausts a large amount of the black smoke. The black smoke includes a large amount of unburned HC, and the TW catalyst 8a cannot purify the HC sufficiently. On the other hand, providing an additional catalyst only for purifying such HC is undesired. Therefore, the diesel engine shown in Fig. 48 performs the lean operation continuously.

Next, the exhaust gas purifying method in this embodiment will be explained with respect to Fig. 49. The exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a is made the lean and

the rich air-fuel ratios  $(A/F)_L$  and  $(A/F)_R$ , alternately and repeatedly. To this end, the reducing agent injection by the reducing agent injector 120b is stopped and the engine 1 performs the lean operation with the lean air-fuel ratio  $(A/F)_L$ , to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to  $(A/F)_L$ . The reducing agent injector 120c injects the reducing agent and the engine 1 performs the lean operation with the lean air-fuel ratio  $(A/F)_L$ , to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to  $(A/F)_R$ . That is, the reducing agent injector 120c injects the reducing agent by an amount required to make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10a, and 10b equal to  $(A/F)_R$ . In this way, the reducing agent injection by the injector 120c is operated and stopped alternately and repeatedly.

Note that, in the above-mentioned embodiment, when the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a is to be made equal to  $(A/F)_L$ , the reducing agent injection is stopped while the engine 1 performs the lean operation with the lean air-fuel ratio  $(A/F)_L$ . Alternatively, the reducing agent injector 120c may inject a very small amount of the reducing agent and the engine 1 may perform the lean operation with the lean air-fuel ratio leaner than  $(A/F)_L$ , to thereby make the exhaust gas air-fuel ratio of the exhaust gas flowing into the catalysts 8a, 10b, and 10a equal to  $(A/F)_L$ .

Also, a burner may be arranged in the exhaust passage upstream of the TW catalyst 8a to consume the oxygen existing in the exhaust gas, to thereby make the exhaust gas air-fuel ratio rich.

According to the present invention, it is possible to provide a method and a device for purifying an exhaust gas of an engine which can purify the exhaust gas

WO 97/17532

PCT/JP96/03205

- 69 -

sufficiently with a simple structure.

While the invention has been described by reference to specific embodiments chosen for purposes of illustration, it should be apparent that numerous  
5 modifications could be made thereto by those skilled in the art without departing from the basic concept and scope of the invention.

WO 97/17532

PCT/JP96/03205

- 70 -

# CLAIMS

1. A method for purifying an exhaust gas of an engine, comprising, in turn:

5 forming an exhaust gas portion of which an exhaust gas air-fuel ratio is lean, and an exhaust gas portion of which the exhaust gas air-fuel ratio is rich, from the exhaust gas of the engine, alternately and repeatedly; and

10 contacting the exhaust gas portions an  $\text{NH}_3$  synthesizing catalyst and an exhaust gas purifying catalyst comprised of at least one selected from the group consisted of an  $\text{NH}_3$  adsorbing and oxidizing ( $\text{NH}_3\text{-AO}$ ) catalyst and a  $\text{NO}_x$  occluding and reducing ( $\text{NO}_x\text{-OR}$ ) catalyst, in turn, the  $\text{NH}_3$  synthesizing catalyst  
15 synthesizing  $\text{NH}_3$  from at least a part of  $\text{NO}_x$  in the inflowing exhaust gas when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich, and passing  $\text{NO}_x$  in the inflowing exhaust gas therethrough when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean,  
20 the  $\text{NH}_3\text{-AO}$  catalyst adsorbing  $\text{NH}_3$  in the inflowing exhaust gas therein, and desorbing the adsorbed  $\text{NH}_3$  therefrom and oxidizing the  $\text{NH}_3$  when an  $\text{NH}_3$  concentration in the inflowing exhaust gas becomes lower, and the  $\text{NO}_x\text{-OR}$  catalyst occluding  $\text{NO}_x$  in the inflowing exhaust  
25 gas therein when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, and releasing the occluded  $\text{NO}_x$  therefrom and reducing the  $\text{NO}_x$  when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich.

30 2. A method according to claim 1, further comprising controlling an engine air-fuel ratio of the engine to make the engine air-fuel ratio lean to thereby form the exhaust gas portion of which the exhaust gas air-fuel ratio is lean, and to make the engine air-fuel ratio rich to thereby form the exhaust gas portion of  
35 which the exhaust gas air-fuel ratio is rich.

3. A method according to claim 2, wherein the engine air-fuel ratio of the engine is made lean for a lean period, and the engine air-fuel ratio of the engine is made rich for a rich period, and wherein the lean and the rich periods are set in accordance with the engine operating condition, respectively.

4. A method according to claim 3, wherein the engine is provided with a plurality of cylinders or cylinder groups of which the exhaust stroke periods are different to each other, and wherein the lean period is set as the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made lean, and the rich period is set as the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich.

5. A method according to claim 4, wherein the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made lean and the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich is set to vary the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich in every cycle, the cycle being formed by one lean period and one rich period which are successive.

6. A method according to claim 4, wherein the lean and the rich period are controlled in accordance with a number ratio which is a ratio of the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made lean to the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich, the number ratio being set in accordance with the engine operating condition.

7. A method according to claim 6, wherein the number ratio is equal to or larger than the total number of the cylinders or cylinder groups of the engine.

8. A method according to claim 6, wherein the number ratio becomes larger as the engine load becomes

WO 97/17532

PCT/JP96/03205

- 72 -

higher when the engine load is low, and becomes smaller as the engine load become higher when the engine load is high.

5 9. A method according to claim 6, wherein the number ratio becomes larger as the intake air amount becomes larger when the intake air amount is small, and becomes smaller as the intake air amount become larger when the intake air amount is large.

10 10. A method according to claim 2, the engine being an internal combustion engine of spark ignition type, and the method further comprising controlling the ignition timing of the engine in accordance with the engine air-fuel ratio of the engine.

15 11. A method according to claim 1, wherein a making-rich device, different from the engine, is arranged in the exhaust passage of an engine upstream of the  $\text{NH}_3$  synthesizing catalyst for making the exhaust gas air-fuel ratio of the exhaust gas of the engine rich, and wherein the method further comprises keeping an engine  
20 air-fuel ratio of the engine lean, and stopping a making-rich operation of the making-rich device to thereby form the exhaust gas of which the exhaust gas air-fuel ratio is lean, and performing the making-rich operation of the making-rich device to thereby form the  
25 exhaust gas of which the exhaust gas air-fuel ratio is rich.

30 12. A method according to claim 11, wherein the making-rich device is provided with: a combustor of which an air-fuel ratio is controllable; and an introducing passage for introducing the exhaust gas of the combustor into the exhaust passage upstream of the  $\text{NH}_3$  synthesizing catalyst, and wherein the making-rich operation of the making-rich device is performed by making an air-fuel ratio of the combustor rich and adding  
35 the exhaust gas of the combustor to the exhaust gas of the engine.

13. A method according to claim 12, wherein the combustor is an auxiliary internal combustion engine having a crank shaft different from that of the engine.

14. A method according to claim 12, wherein the combustor is a burner.

15. A method according to claim 11, wherein the making-rich device is provided with a reducing agent injector for feeding a reducing agent into the exhaust passage upstream of the  $\text{NH}_3$  synthesizing catalyst, the making-rich operation of the reducing agent injector being performed by adding the reducing agent to the exhaust gas of the engine.

16. A method according to claim 15, wherein the reducing agent is a hydrocarbon such as gasoline, isooctane, hexane, heptane, gas oil, and kerosene or a hydrocarbon which can be stored in a liquid state, such as butane or propane.

17. A method according to claim 1, wherein the exhaust gas purifying catalyst is comprised of at least the  $\text{NH}_3$ -AO catalyst, wherein the method further comprises estimating an amount of  $\text{NH}_3$  adsorbed in the  $\text{NH}_3$ -AO catalyst, and wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from lean to rich or from rich to lean in accordance with the estimated adsorbed  $\text{NH}_3$  amount.

18. A method according to claim 17, wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from rich to lean when the estimated adsorbed  $\text{NH}_3$  amount exceeds over a predetermined upper threshold.

19. A method according to claim 17, wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from lean to rich when the estimated adsorbed  $\text{NH}_3$  amount falls below a predetermined lower threshold.

20. A method according to claim 17, wherein the adsorbed  $\text{NH}_3$  amount is estimated on the basis of an  $\text{NH}_3$  amount flowing into the  $\text{NH}_3$ -AO catalyst when the exhaust gas air-fuel ratio of the exhaust gas flowing into the  $\text{NH}_3$ -AO catalyst is rich, and on the basis of the desorbed  $\text{NH}_3$  amount when the exhaust gas air-fuel ratio of the exhaust gas flowing into the  $\text{NH}_3$ -AO catalyst is lean.

21. A method according to claim 20, wherein the  $\text{NH}_3$  amount flowing into the  $\text{NH}_3$ -AO catalyst is estimated on the basis of a  $\text{NO}_x$  amount flowing into the  $\text{NH}_3$  synthesizing catalyst and an  $\text{NH}_3$  synthesizing efficiency of the  $\text{NH}_3$  synthesizing catalyst.

22. A method according to claim 1, wherein the exhaust gas purifying catalyst is comprised of at least the  $\text{NO}_x$ -OR catalyst, wherein the method further comprises estimating an amount of  $\text{NO}_x$  occluded in the  $\text{NO}_x$ -OR catalyst, and wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from lean to rich or from rich to lean in accordance with the estimated occluded  $\text{NO}_x$  amount.

23. A method according to claim 22, wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from lean to rich when the estimated occluded  $\text{NO}_x$  amount exceeds over a predetermined upper threshold.

24. A method according to claim 22, wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from rich to lean when the estimated occluded  $\text{NO}_x$  amount falls below a predetermined lower threshold.

25. A method according to claim 22, wherein the occluded  $\text{NO}_x$  amount is estimated on the basis of a  $\text{NO}_x$  amount flowing into the  $\text{NO}_x$ -OR catalyst when the exhaust gas air-fuel ratio of the exhaust gas flowing into the



WO 97/17532

PCT/JP96/03205

- 75 -

NO<sub>x</sub>-OR catalyst is lean, and on the basis of the released NO<sub>x</sub> amount when the exhaust gas air-fuel ratio of the exhaust gas flowing into the NO<sub>x</sub>-OR catalyst is rich.

26. A method according to claim 1, wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from lean to rich or from rich to lean in accordance with the engine operating condition.

27. A method according to claim 1, wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from lean to rich or from rich to lean gradually with a changing rate.

28. A method according to claim 27, wherein the changing rate when the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from lean to rich is larger than that when the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is changed from rich to lean.

29. A method according to claim 27, wherein the changing rate is set in accordance with the engine operating condition.

30. A method according to claim 29, wherein the changing rate becomes smaller as the engine load becomes higher.

31. A method according to claim 1, wherein the exhaust gas air-fuel ratio of the exhaust gas portion is set in accordance with the engine operating condition.

32. A method according to claim 31, wherein the exhaust gas air-fuel ratio of the exhaust gas portion of which the exhaust gas air-fuel ratio is lean becomes larger as the engine load becomes higher when the engine load is low, and becomes smaller as the engine load becomes higher when the engine load is high.

33. A method according to claim 31, wherein the exhaust gas air-fuel ratio of the exhaust gas portion of

which the exhaust gas air-fuel ratio is rich becomes smaller when the intake air amount of the engine becomes larger.

5           34. A method according to claim 1, wherein the exhaust gas air-fuel ratio of one of the exhaust gas portions is set in accordance with the exhaust gas air-fuel ratio of the other.

10           35. A method according to claim 1, wherein a period during which the exhaust gas portion of which the exhaust gas air-fuel ratio is lean is formed, is longer than that during which the exhaust gas portion of which the exhaust gas air-fuel ratio is rich is formed.

15           36. A method according to claim 1, wherein the exhaust gas air-fuel ratio of the exhaust gas portion to be contacted with the catalysts is made equal to a target air-fuel ratio on the basis of output signals of an air-fuel ratio sensor arranged in an exhaust passage of the engine adjacent to an inlet of the  $\text{NH}_3$  synthesizing catalyst.

20           37. A method according to claim 1, the engine further having a muffler arranged in an exhaust passage thereof, wherein the exhaust gas purifying catalyst is comprised of at least the  $\text{NH}_3$ -AO catalyst, and wherein the  $\text{NH}_3$ -AO catalyst is housed in the muffler.

25           38. A method according to claim 1, wherein the exhaust gas purifying catalyst is comprised of at least the  $\text{NO}_x$ -OR catalyst, and wherein the  $\text{NH}_3$  synthesizing catalyst and the  $\text{NO}_x$ -OR catalyst are carried on a common substrate.

30           39. A method according to claim 1, wherein the exhaust gas purifying catalyst is comprised of both of the  $\text{NH}_3$ -AO catalyst and the  $\text{NO}_x$ -OR catalyst, and wherein the  $\text{NH}_3$ -AO catalyst and the  $\text{NO}_x$ -OR catalyst are arranged in an exhaust passage of the engine, in series.

35           40. A method according to claim 39, wherein the  $\text{NH}_3$ -AO catalyst is arranged in the exhaust passage

downstream of the NO<sub>x</sub>-OR catalyst.

41. A method according to claim 1, wherein the exhaust gas purifying catalyst is comprised of both of the NH<sub>3</sub>-AO catalyst and the NO<sub>x</sub>-OR catalyst, and wherein  
5 the NH<sub>3</sub>-AO catalyst and the NO<sub>x</sub>-OR catalyst are laminated to each other on a common substrate.

42. A method according to claim 1, wherein the NH<sub>3</sub> synthesizing catalyst is a three-way catalyst including at least one precious metal such as palladium, platinum,  
10 and rhodium.

43. A method according to claim 1, wherein the NO<sub>x</sub>-OR catalyst includes: at least one substance selected from alkali metals such as potassium, sodium, lithium, and cesium, alkali earth metals such as barium  
15 and calcium, rare earth metals such as lanthanum and yttrium, and transition metals such as iron and copper; and precious metals such as palladium, platinum, and rhodium.

44. A method according to claim 1, further  
20 comprising contacting the exhaust gas portions an NH<sub>3</sub> purifying catalyst for purifying NH<sub>3</sub> in the inflowing exhaust gas, after contacting the exhaust gas portions the exhaust gas purifying catalyst.

45. A method according to claim 44, wherein the NH<sub>3</sub>  
25 purifying catalyst includes at least one substance selected from precious metals such as palladium, platinum, and rhodium, and transition metals such as iron and copper.

46. A method according to claim 44, the NH<sub>3</sub>  
30 purifying catalyst purifying NH<sub>3</sub> under the oxidizing atmosphere, wherein the method further comprises keeping the exhaust gas air-fuel ratio of the exhaust gas flowing into the NH<sub>3</sub> purifying catalyst lean.

47. A device for purifying an exhaust gas of an  
35 engine having an exhaust passage, comprising:

WO 97/17532

PCT/JP96/03205

- 78 -

exhaust gas portion forming means arranged in the engine or the exhaust passage for forming an exhaust gas portion of which an exhaust gas air-fuel ratio is lean, and an exhaust gas portion of which the exhaust gas air-fuel ratio is rich, from the exhaust gas of the engine, alternately and repeatedly;

an  $\text{NH}_3$  synthesizing catalyst arranged in the exhaust passage downstream of the exhaust gas portion forming means, the  $\text{NH}_3$  synthesizing catalyst synthesizing  $\text{NH}_3$  from at least a part of  $\text{NO}_x$  in the inflowing exhaust gas when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich, and passing  $\text{NO}_x$  in the inflowing exhaust gas therethrough when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean; and

an exhaust gas purifying catalyst arranged in the exhaust passage downstream of the  $\text{NH}_3$  synthesizing catalyst, the exhaust gas purifying catalyst comprising at least one selected from the group consisting of an  $\text{NH}_3$  adsorbing and oxidizing ( $\text{NH}_3\text{-AO}$ ) catalyst and a  $\text{NO}_x$  occluding and reducing ( $\text{NO}_x\text{-OR}$ ) catalyst, the  $\text{NH}_3\text{-AO}$  catalyst adsorbing  $\text{NH}_3$  in the inflowing exhaust gas therein, and desorbing the adsorbed  $\text{NH}_3$  therefrom and oxidizing the  $\text{NH}_3$  when the  $\text{NH}_3$  concentration in the inflowing exhaust gas becomes lower, and the  $\text{NO}_x\text{-OR}$  catalyst occluding  $\text{NO}_x$  in the inflowing exhaust gas therein when the exhaust gas air-fuel ratio of the inflowing exhaust gas is lean, and releasing the occluded  $\text{NO}_x$  therefrom and reducing the  $\text{NO}_x$  when the exhaust gas air-fuel ratio of the inflowing exhaust gas is rich.

48. A device according to claim 47, wherein the exhaust gas portion forming means comprises an engine air-fuel ratio control means for controlling an engine air-fuel ratio of the engine to make the engine air-fuel ratio lean to thereby form the exhaust gas portion of which the exhaust gas air-fuel ratio is lean, and to make

the engine air-fuel ratio rich to thereby form the exhaust gas portion of which the exhaust gas air-fuel ratio is rich.

49. A device according to claim 48, wherein the engine air-fuel ratio control means makes the engine air-fuel ratio lean for a lean period, and makes the engine air-fuel ratio rich for a rich period, and wherein the lean and the rich periods are set in accordance with the engine operating condition, respectively.

50. A device according to claim 49, wherein the engine is provided with a plurality of cylinders or cylinder groups of which the exhaust stroke periods are different to each other, and wherein the lean period is set as the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made lean, and the rich period is set as the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich.

51. A device according to claim 50, wherein the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made lean and the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich are set to vary the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich in every cycle, the cycle being formed by one lean period and one rich period which are successive.

52. A device according to claim 50, wherein the lean and the rich period are controlled in accordance with a number ratio which is a ratio of the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made lean to the number of the cylinders or cylinder groups of which the engine air-fuel ratio is to be made rich, the number ratio being set in accordance with the engine operating condition.

53. A device according to claim 52, wherein the number ratio is equal to or larger than the total number

WO 97/17532

PCT/JP96/03205

- 80 -

of the cylinders or cylinder groups of the engine.

54. A device according to claim 52, wherein the number ratio becomes larger as the engine load becomes higher when the engine load is low, and becomes smaller as the engine load become higher when the engine load is high.

55. A device according to claim 52, wherein the number ratio becomes larger as the intake air amount becomes larger when the intake air amount is small, and becomes smaller as the intake air amount become larger when the intake air amount is large.

56. A device according to claim 48, the engine being an internal combustion engine of spark ignition type, and the device further comprising ignition timing control means for controlling the ignition timing of the engine in accordance with the engine air-fuel ratio of the engine.

57. A device according to claim 47, wherein the exhaust gas portion forming means comprises making-rich means, different from the engine, arranged in the exhaust passage upstream of the  $\text{NH}_3$  synthesizing catalyst for making the exhaust gas air-fuel ratio of the exhaust gas of the engine rich, and keeping means for keeping the engine air-fuel ratio of the engine lean, and wherein the making-rich means stops a making-rich operation thereof to thereby form the exhaust gas of which the exhaust gas air-fuel ratio is lean, and performs the making-rich operation thereof to thereby form the exhaust gas of which the exhaust gas air-fuel ratio is rich.

58. A device according to claim 57, wherein the making-rich means comprises: a combustor of which an air-fuel ratio is controllable; and an introducing passage for introducing the exhaust gas of the combustor into the exhaust passage upstream of the  $\text{NH}_3$  synthesizing catalyst, and wherein the making-rich means performs the making-rich operation thereof by making an air-fuel ratio

of the combustor rich and adding the exhaust gas of the combustor to the exhaust gas of the engine.

59. A device according to claim 58, wherein the combustor is an auxiliary internal combustion engine  
5 having a crank shaft different from that of the engine.

60. A device according to claim 58, wherein the combustor is a burner.

61. A device according to claim 57, wherein the making-rich means comprises a reducing agent injector for  
10 feeding a reducing agent into the exhaust passage upstream of the  $\text{NH}_3$  synthesizing catalyst, the reducing agent injector performing the making-rich operation thereof by adding the reducing agent to the exhaust gas of the engine.

62. A device according to claim 61, wherein the reducing agent is a hydrocarbon such as gasoline, isooctane, hexane, heptane, gas oil, and kerosene or a hydrocarbon which can be stored in a liquid state, such as butane or propane.

63. A device according to claim 47, wherein the exhaust gas purifying catalyst comprises at least the  $\text{NH}_3$ -AO catalyst, wherein the device further comprises adsorbed  $\text{NH}_3$  amount estimating means for estimating an amount of  $\text{NH}_3$  adsorbed in the  $\text{NH}_3$ -AO catalyst, and  
20 wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from lean to rich or from rich to lean in accordance with the estimated adsorbed  $\text{NH}_3$  amount.

64. A device according to claim 63, wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from rich to lean when the estimated adsorbed  $\text{NH}_3$  amount exceeds a predetermined upper threshold.

65. A device according to claim 63, wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby  
35

from lean to rich when the estimated adsorbed  $\text{NH}_3$  amount falls below a predetermined lower threshold.

66. A device according to claim 63, wherein the adsorbed  $\text{NH}_3$  amount estimating means estimates the  
5 adsorbed  $\text{NH}_3$  amount on the basis of an  $\text{NH}_3$  amount flowing into the  $\text{NH}_3$ -AO catalyst when the exhaust gas air-fuel ratio of the exhaust gas flowing into the  $\text{NH}_3$ -AO catalyst is rich, and on the basis of the desorbed  $\text{NH}_3$  amount when  
10 the exhaust gas air-fuel ratio of the exhaust gas flowing into the  $\text{NH}_3$ -AO catalyst is lean.

67. A device according to claim 66, wherein the adsorbed  $\text{NH}_3$  amount estimating means estimates the  $\text{NH}_3$  amount flowing into the  $\text{NH}_3$ -AO catalyst on the basis of a  
15  $\text{NO}_x$  amount flowing into the  $\text{NH}_3$  synthesizing catalyst and an  $\text{NH}_3$  synthesizing efficiency of the  $\text{NH}_3$  synthesizing catalyst.

68. A device according to claim 47, wherein the exhaust gas purifying catalyst comprises at least the  $\text{NO}_x$ -OR catalyst, wherein the device further comprises  
20 occluded  $\text{NO}_x$  amount estimating means for estimating an amount of  $\text{NO}_x$  occluded in the  $\text{NO}_x$ -OR catalyst, and wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from lean to rich or from rich to lean in  
25 accordance with the estimated occluded  $\text{NO}_x$  amount.

69. A device according to claim 68, wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from lean to rich when the estimated occluded  $\text{NO}_x$  amount  
30 exceeds a predetermined upper threshold.

70. A device according to claim 68, wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from rich to lean when the estimated occluded  $\text{NO}_x$  amount  
35 falls below a predetermined lower threshold.



71. A device according to claim 68, wherein the occluded NO<sub>x</sub> amount estimating means estimates the occluded NO<sub>x</sub> amount on the basis of a NO<sub>x</sub> amount flowing into the NO<sub>x</sub>-OR catalyst when the exhaust gas air-fuel ratio of the exhaust gas flowing into the NO<sub>x</sub>-OR catalyst is lean, and on the basis of the released NO<sub>x</sub> amount when the exhaust gas air-fuel ratio of the exhaust gas flowing into the NO<sub>x</sub>-OR catalyst is rich.

72. A device according to claim 47, wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from lean to rich or from rich to lean in accordance with the engine operating condition.

73. A device according to claim 47, wherein the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from lean to rich or from rich to lean gradually with a changing rate.

74. A device according to claim 73, wherein the changing rate when the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from lean to rich is larger than that when the exhaust gas portion forming means changes the exhaust gas air-fuel ratio of the exhaust gas portion formed thereby from rich to lean.

75. A device according to claim 73, wherein the changing rate is set in accordance with the engine operating condition.

76. A device according to claim 75, wherein the changing rate becomes smaller as the engine load becomes higher.

77. A device according to claim 47, wherein the exhaust gas air-fuel ratio of the exhaust gas portion is set in accordance with the engine operating condition.

78. A device according to claim 77, wherein the exhaust gas air-fuel ratio of the exhaust gas portion of

which the exhaust gas air-fuel ratio is lean becomes larger as the engine load becomes higher when the engine load is low, and becomes smaller as the engine load becomes higher when the engine load is high.

5           79. A device according to claim 77, wherein the exhaust gas air-fuel ratio of the exhaust gas portion of which the exhaust gas air-fuel ratio is rich becomes smaller when the intake air amount of the engine becomes larger.

10           80. A device according to claim 47, wherein the exhaust gas air-fuel ratio of one of the exhaust gas portions is set in accordance with the exhaust gas air-fuel ratio of the other.

15           81. A device according to claim 47, wherein a period during which the exhaust gas portion forming means forms the exhaust gas portion of which the exhaust gas air-fuel ratio is lean is longer than that during which the exhaust gas portion forming means forms the exhaust gas portion of which the exhaust gas air-fuel ratio is rich.

20           82. A device according to claim 47, further comprising an air-fuel ratio sensor arranged in the exhaust passage between the exhaust gas portion forming means and the  $\text{NH}_3$  synthesizing catalyst, and wherein the exhaust gas portion forming means makes the exhaust gas air-fuel ratio the exhaust gas portions formed thereby equal to a target air-fuel ratio on the basis of the output signals of the air-fuel ratio sensor.

25           83. A device according to claim 47, the engine further having a muffler arranged in the exhaust passage, wherein the exhaust gas purifying catalyst comprises at least the  $\text{NH}_3$ -AO catalyst, and wherein the  $\text{NH}_3$ -AO catalyst is housed in the muffler.

30           84. A device according to claim 47, wherein the exhaust gas purifying catalyst comprises at least the  $\text{NO}_x$ -OR catalyst, and wherein the  $\text{NH}_3$  synthesizing

catalyst and the NO<sub>x</sub>-OR catalyst are carried on a common substrate.

85. A device according to claim 47, wherein the exhaust gas purifying catalyst comprises both of the  
5 NH<sub>3</sub>-AO catalyst and the NO<sub>x</sub>-OR catalyst, and wherein the NH<sub>3</sub>-AO catalyst and the NO<sub>x</sub>-OR catalyst are arranged in the exhaust passage in series.

86. A device according to claim 85, wherein the NH<sub>3</sub>-AO catalyst is arranged in the exhaust passage  
10 downstream of the NO<sub>x</sub>-OR catalyst.

87. A device according to claim 47, wherein the exhaust gas purifying catalyst comprises both of the NH<sub>3</sub>-AO catalyst and the NO<sub>x</sub>-OR catalyst, and wherein the NH<sub>3</sub>-AO catalyst and the NO<sub>x</sub>-OR catalyst are laminated to  
15 each other on a common substrate.

88. A device according to claim 47, wherein the NH<sub>3</sub> synthesizing catalyst is a three-way catalyst including at least one precious metal such as palladium, platinum, and rhodium.

89. A device according to claim 47, wherein the NO<sub>x</sub>OR catalyst includes: at least one substance selected from alkali metals such as potassium, sodium, lithium, and cesium, alkali earth metals such as barium and calcium, rare earth metals such as lanthanum and yttrium,  
20 and transition metals such as iron and copper; and precious metals such as palladium, platinum, and rhodium.

90. A device according to claim 47, further comprising an NH<sub>3</sub> purifying catalyst arranged downstream of the exhaust gas purifying catalyst for purifying NH<sub>3</sub>,  
30 in the inflowing exhaust gas.

91. A device according to claim 90, wherein the NH<sub>3</sub> purifying catalyst includes at least one substance selected from precious metals such as palladium, platinum, and rhodium, and transition metals such as iron  
35 and copper.

WO 97/17532

PCT/JP96/03205

- 86 -

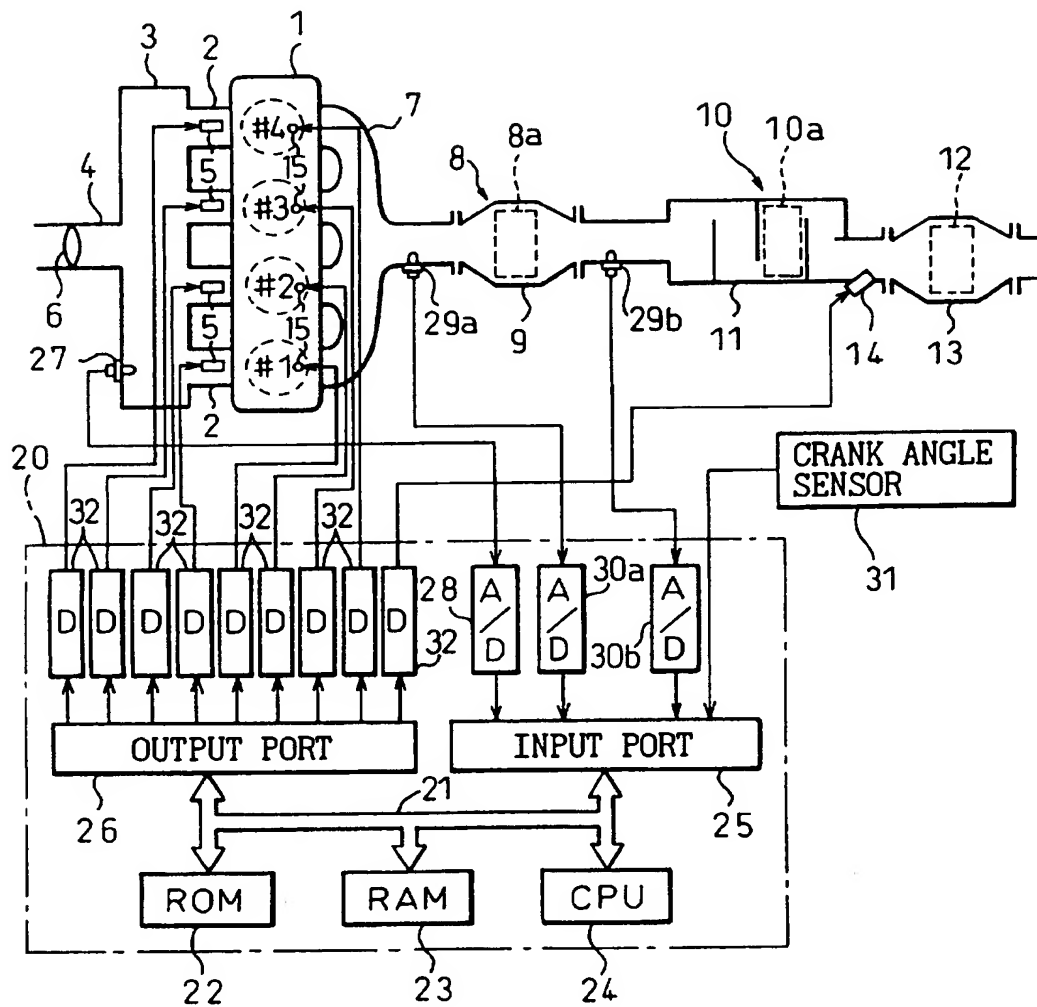
92. A device according to claim 90, the NH<sub>3</sub> purifying catalyst purifying NH<sub>3</sub> under the oxidizing atmosphere, wherein the device further comprises keeping-lean means arranged in the exhaust passage between the exhaust gas purifying catalyst and the NH<sub>3</sub> purifying catalyst for keeping the exhaust gas air-fuel ratio of the exhaust gas flowing into the NH<sub>3</sub> purifying catalyst lean.

WO 97/17532

PCT/JP96/03205

1/44

Fig. 1



WO 97/17532

PCT/JP96/03205

2/44

Fig.2A

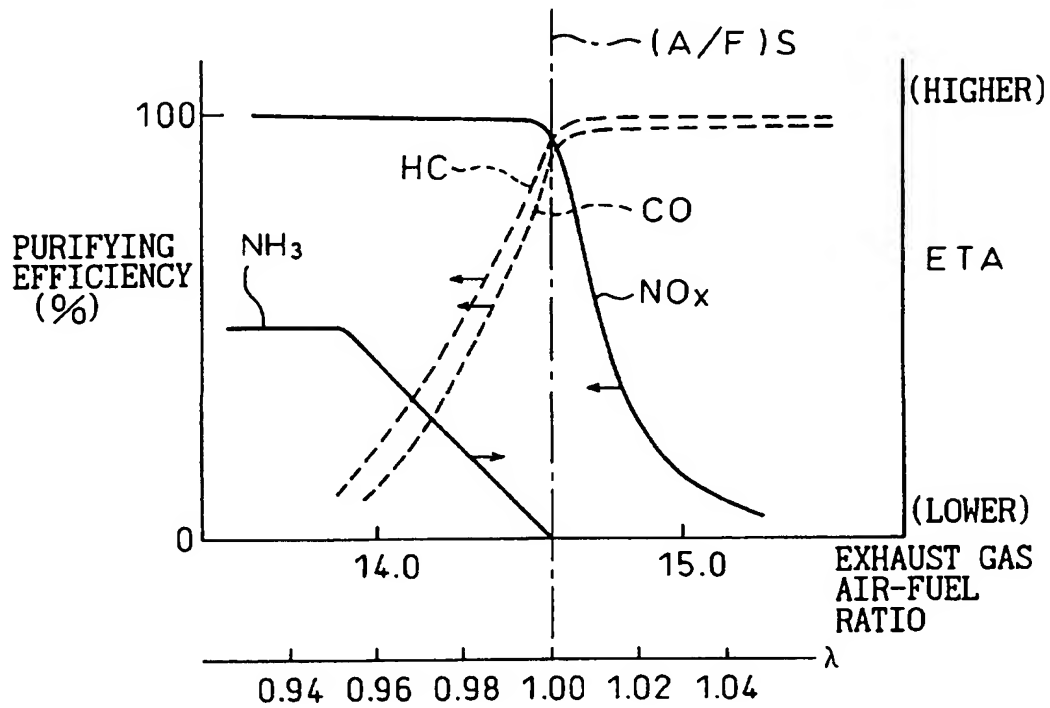
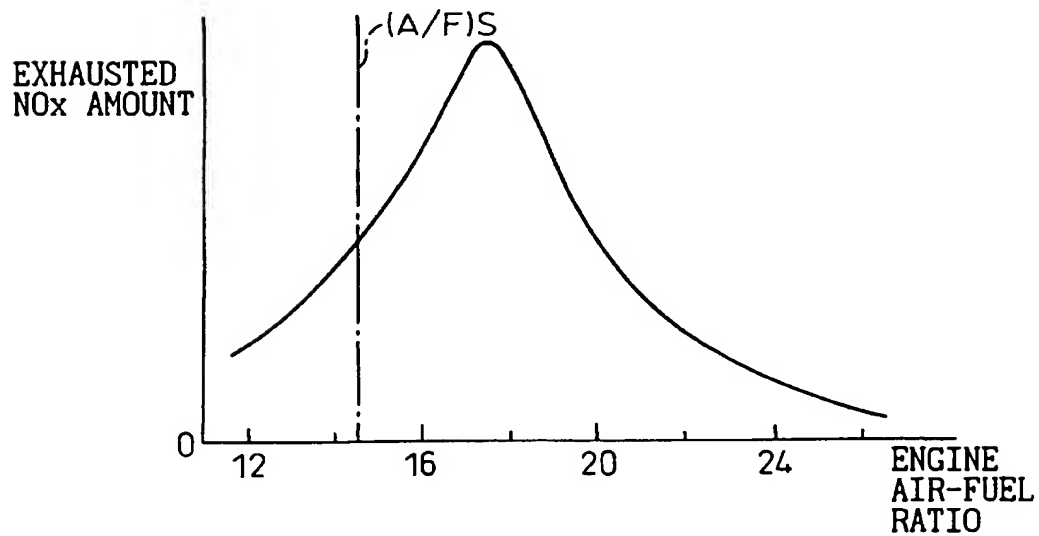


Fig.2B

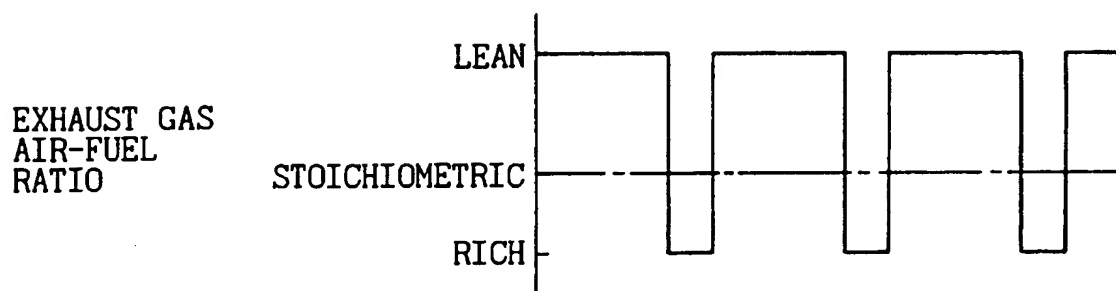


WO 97/17532

PCT/JP96/03205

3/  
44

Fig.3



4/46

Fig. 4A

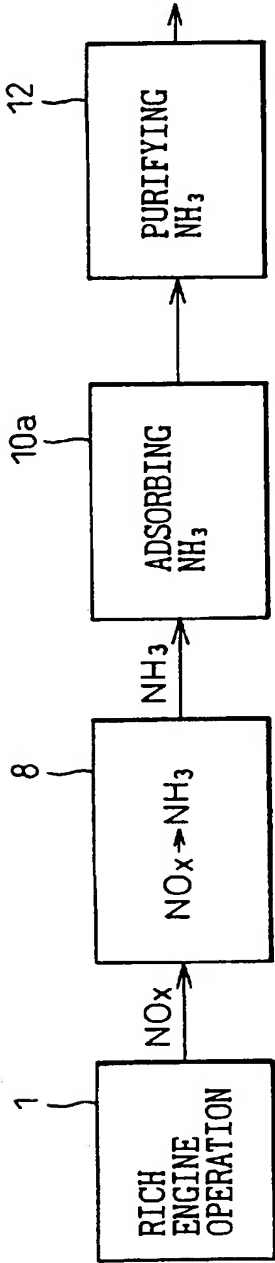
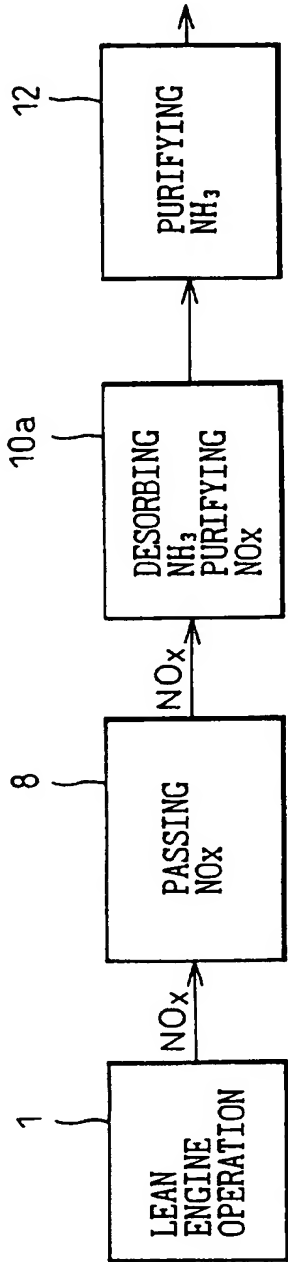


Fig. 4B



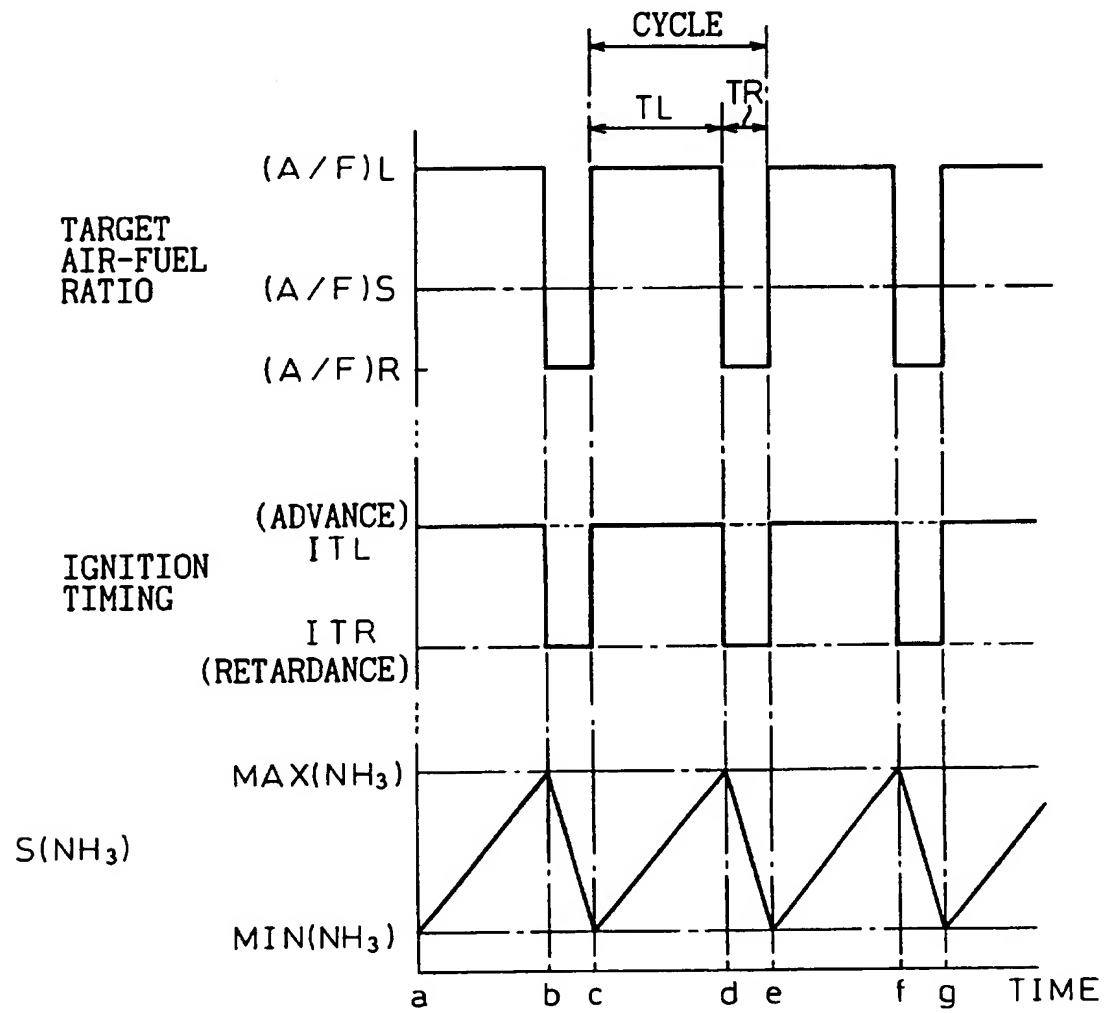


WO 97/17532

PCT/JP96/03205

5/44

Fig.5



WO 97/17532

PCT/JP96/03205

6/  
44

Fig.6A

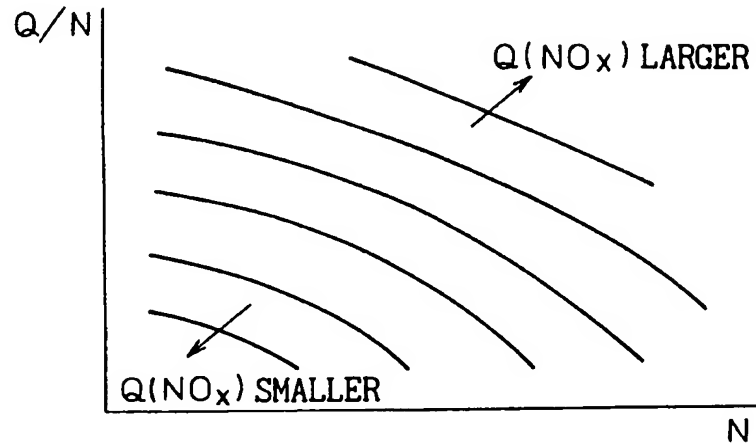
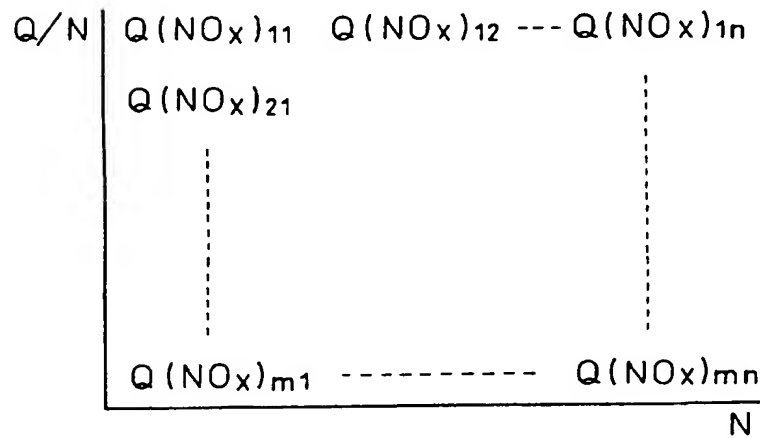


Fig.6B

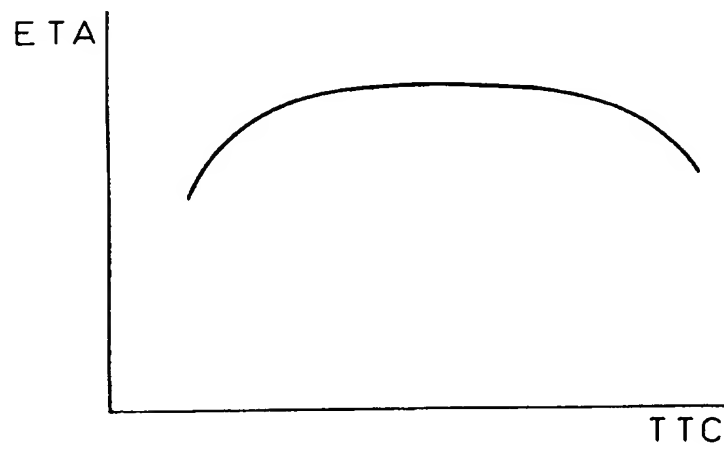


WO 97/17532

PCT/JP96/03205

7/  
44

Fig.7



WO 97/17532

PCT/JP96/03205

8/  
44

Fig.8A

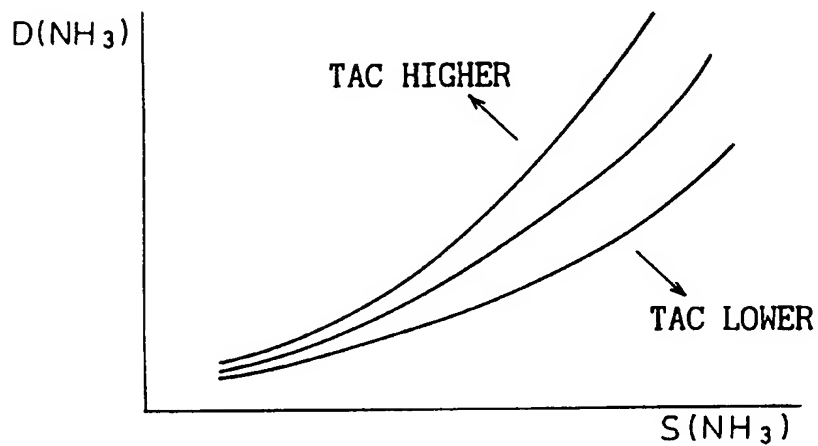
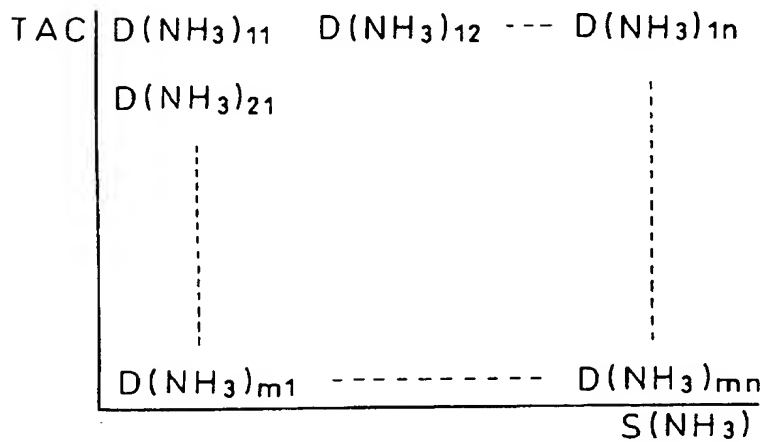


Fig.8B



WO 97/17532

PCT/JP96/03205

9/44

Fig.9A

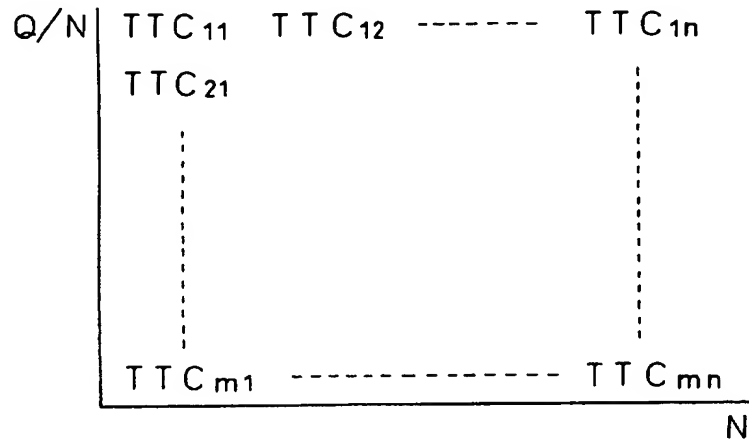
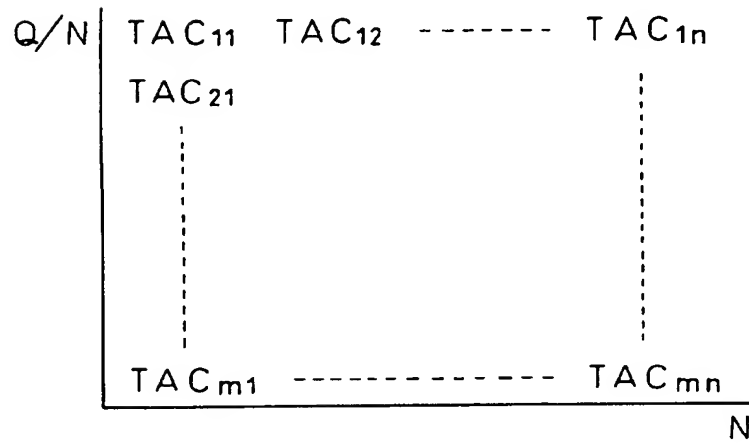


Fig.9B

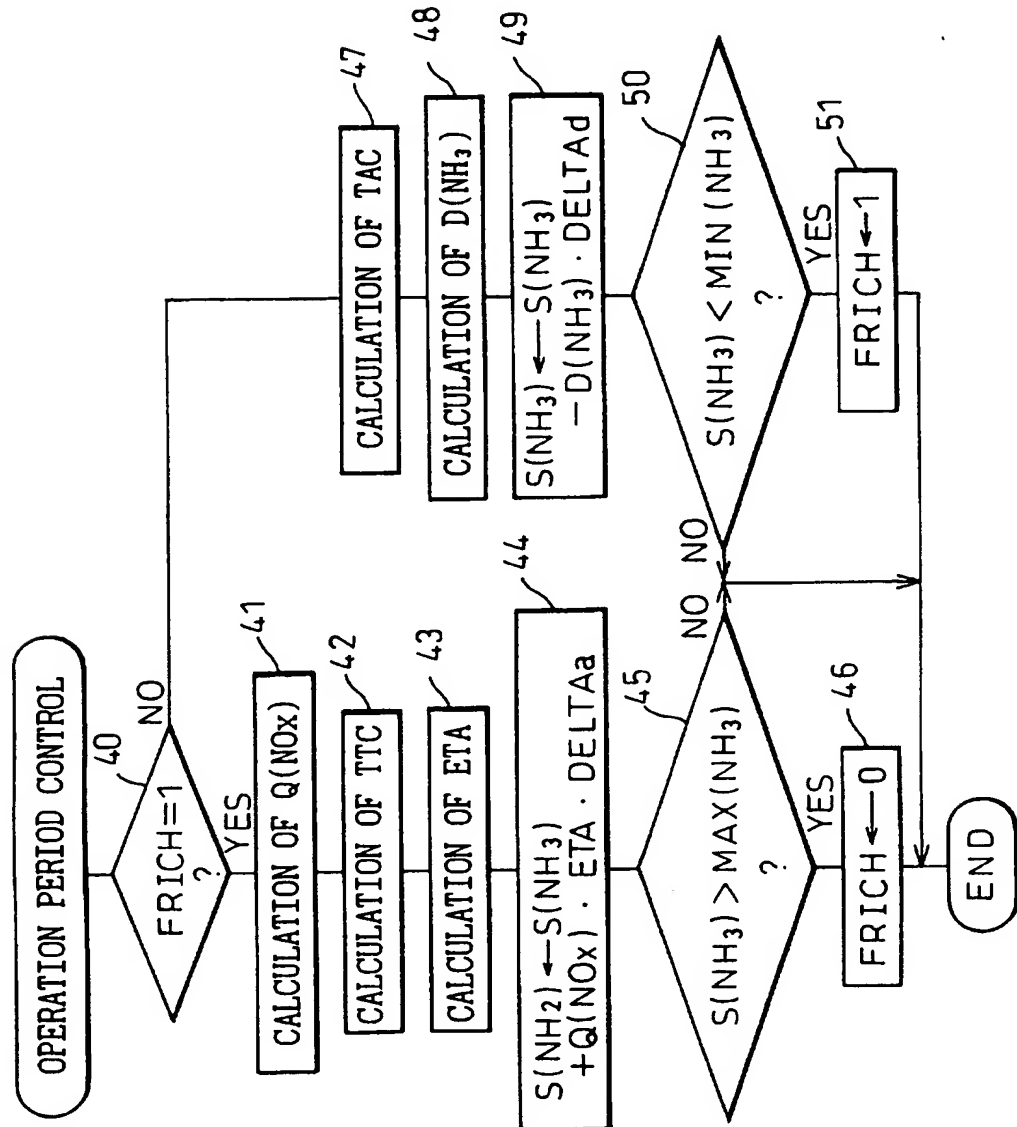


WO 97/17532

PCT/JP96/03205

10/44

Fig.10

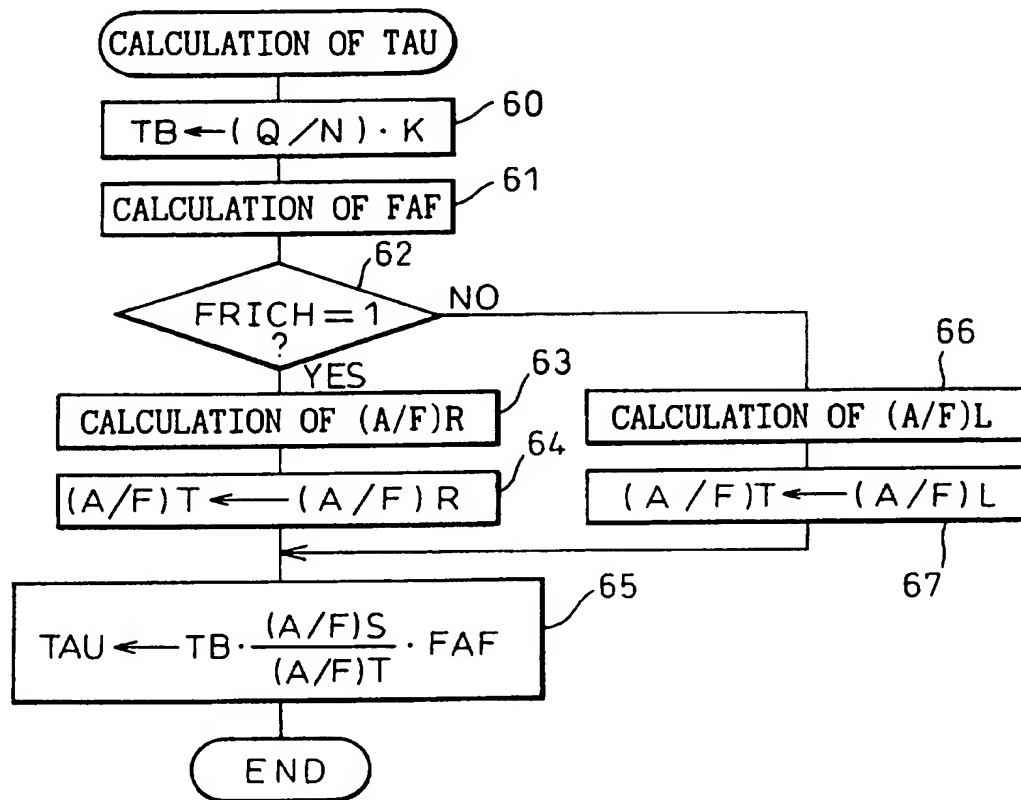


WO 97/17532

PCT/JP96/03205

11/44

Fig.11



WO 97/17532

PCT/JP96/03205

12/44

Fig. 12

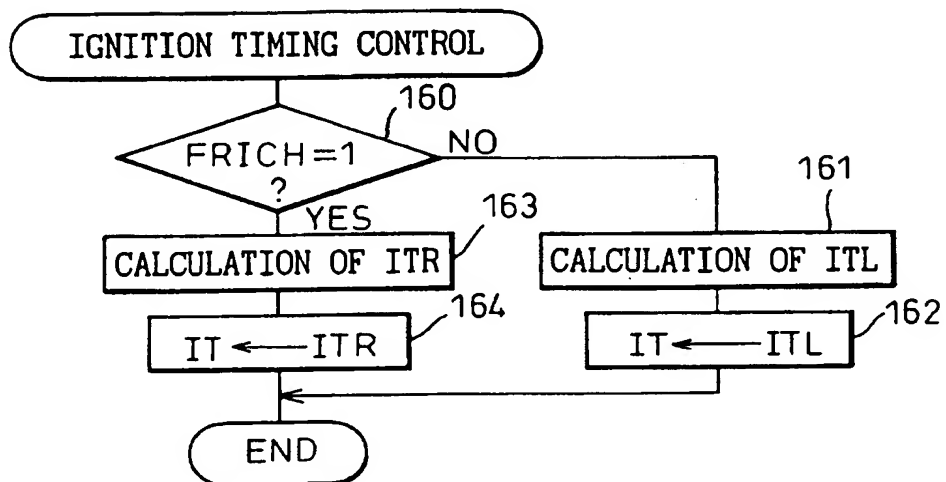
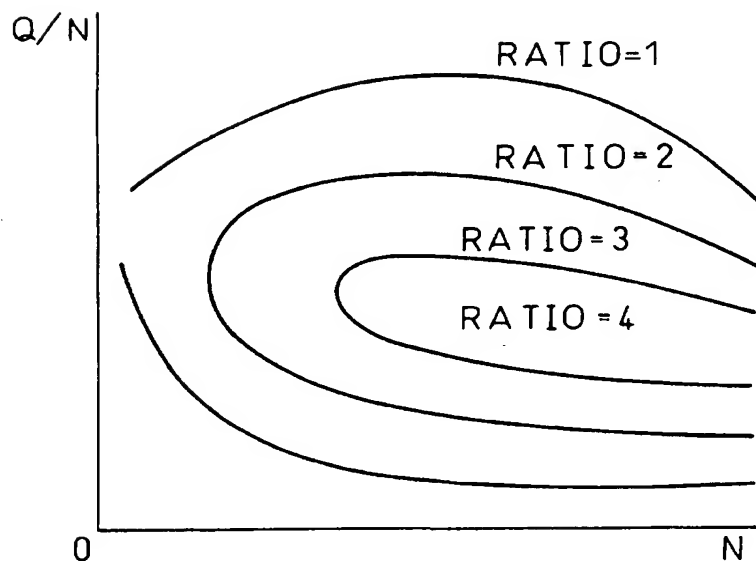


Fig. 13





WO 97/17532

PCT/JP96/03205

13/44

Fig.14

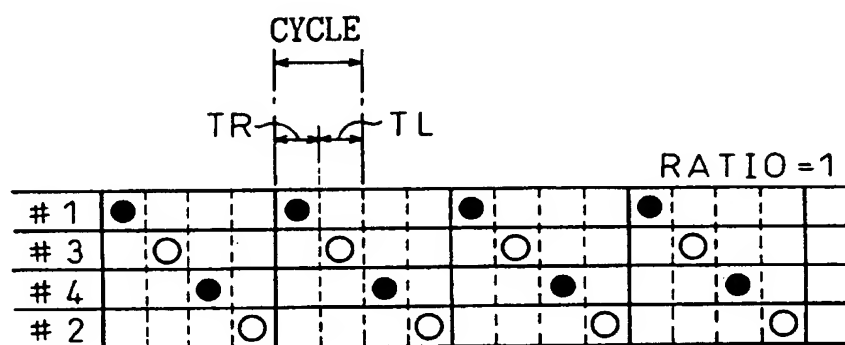
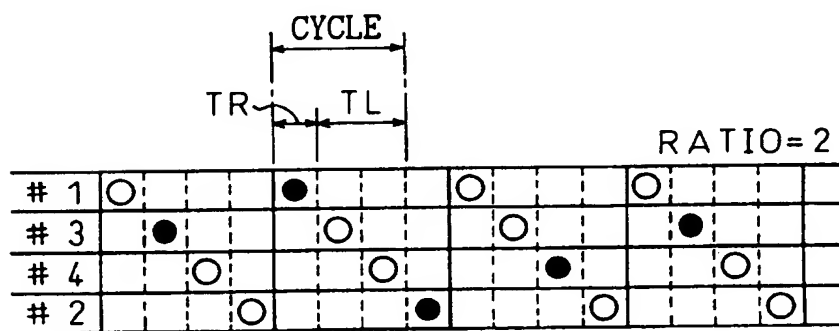


Fig.15



WO 97/17532

PCT/JP96/03205

$\frac{14}{44}$

Fig.16

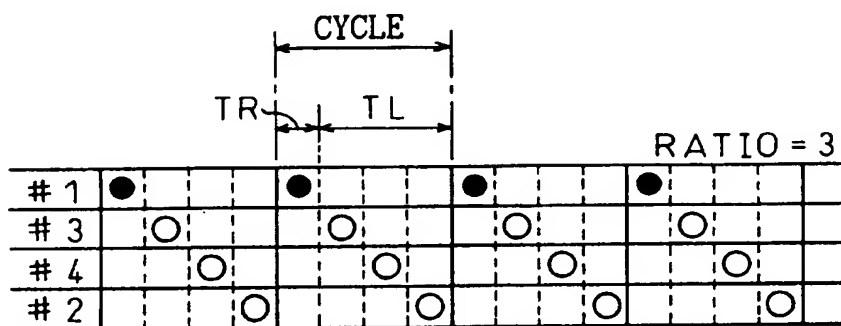
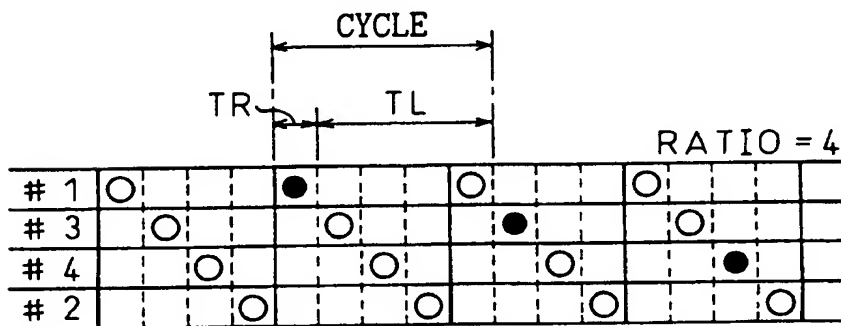


Fig.17



WO 97/17532

PCT/JP96/03205

$\frac{15}{44}$

Fig.18

RATIO	1	2	3	4
DRATIO	00001	00011	00111	01111

Fig.19

RATIO = 2

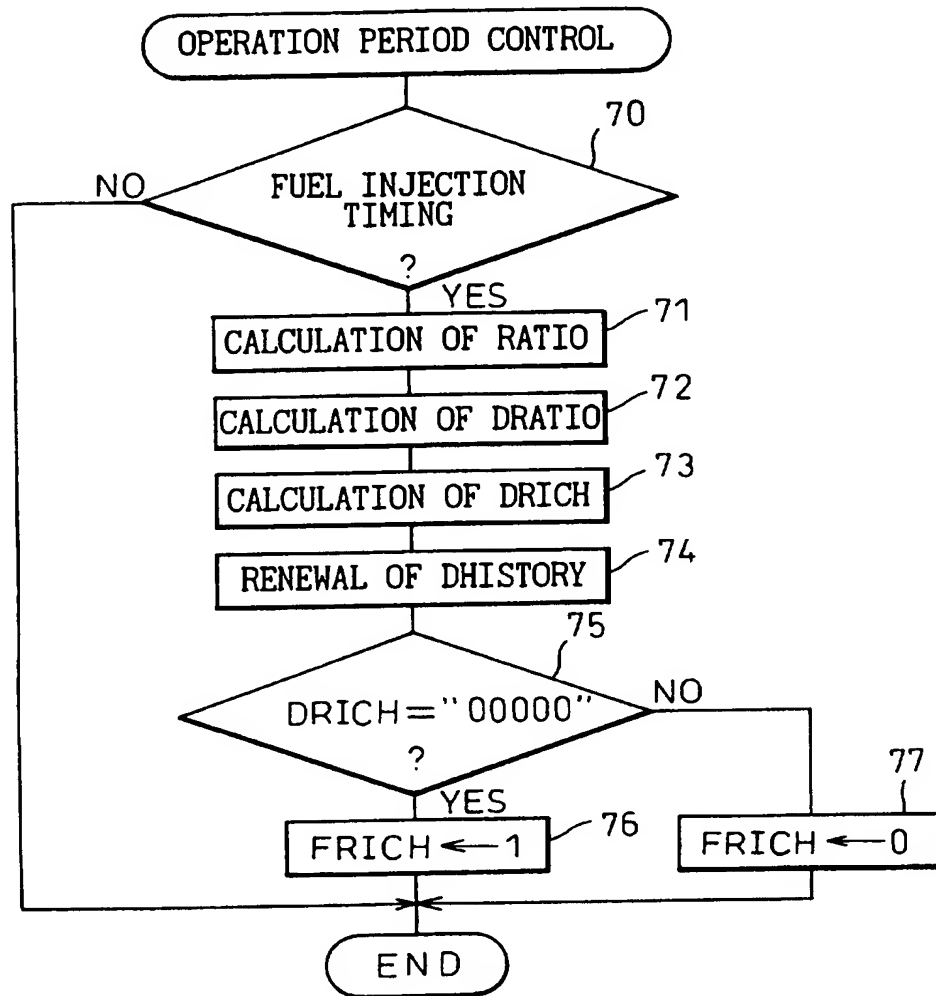
CYLINDER	# 2	# 1	# 3	# 4	# 2	# 1
DHISTORY	10010	00100	01001	10010	00100	01001
DRATIO	00011	00011	00011	00011	00011	00011
DRICH	00010	00000	00001	00010	00000	00001

WO 97/17532

PCT/JP96/03205

16/  
44

Fig. 20



WO 97/17532

PCT/JP96/03205

$\frac{17}{44}$

Fig.21

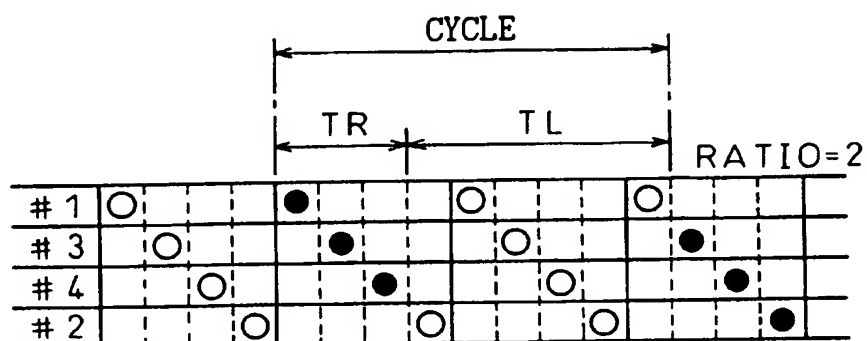
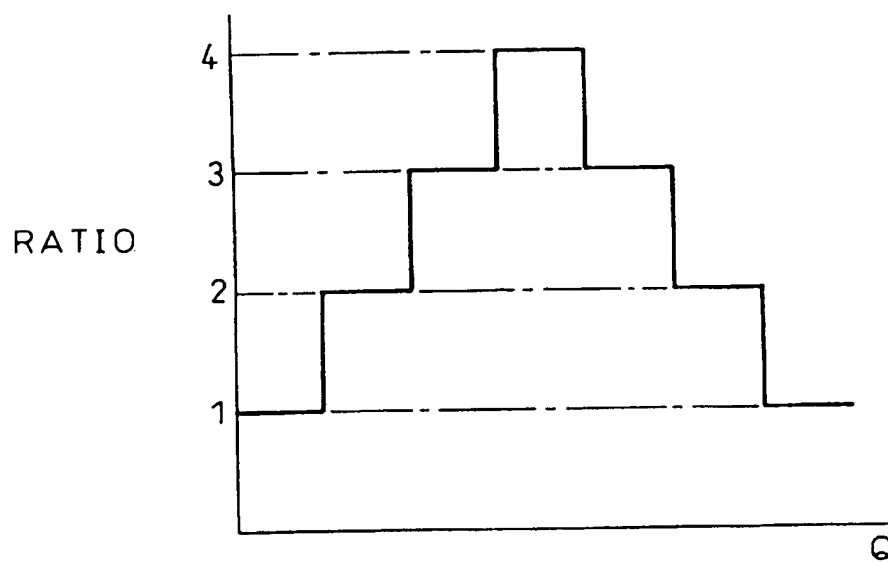


Fig.22



WO 97/17532

PCT/JP96/03205

$\frac{18}{44}$

Fig.23

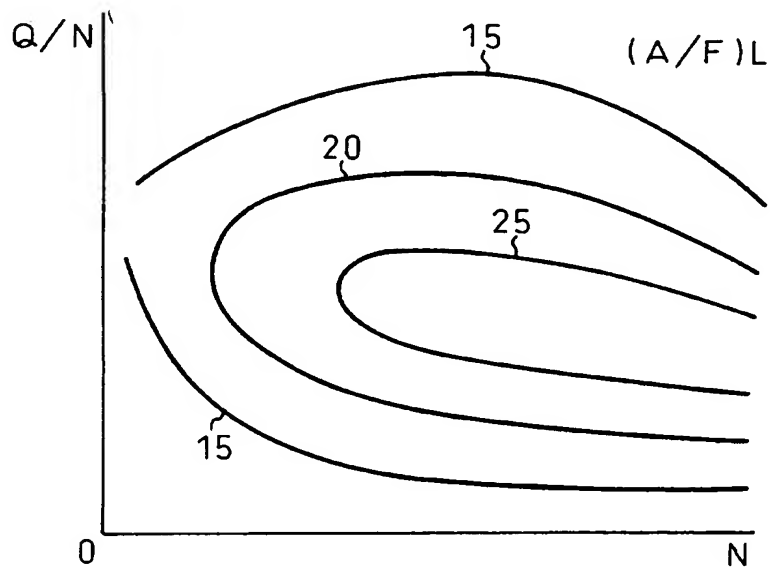
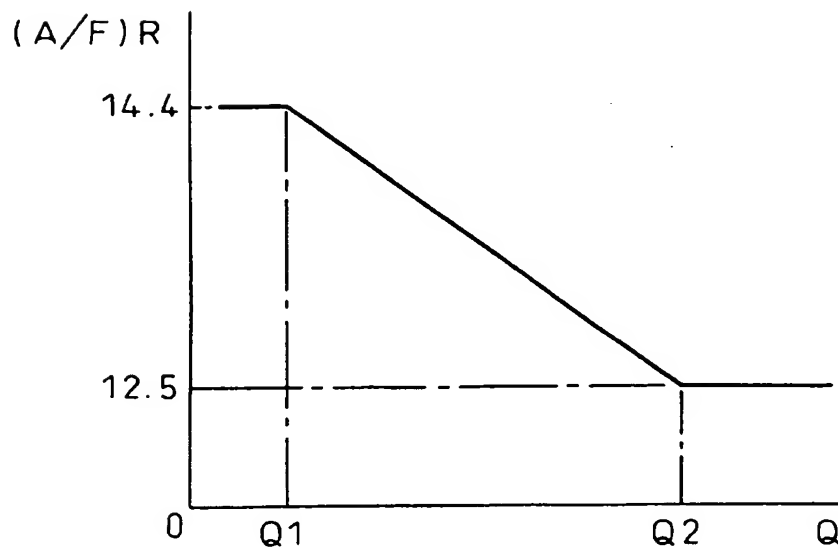


Fig.24



WO 97/17532

PCT/JP96/03205

19/  
44

Fig .25A

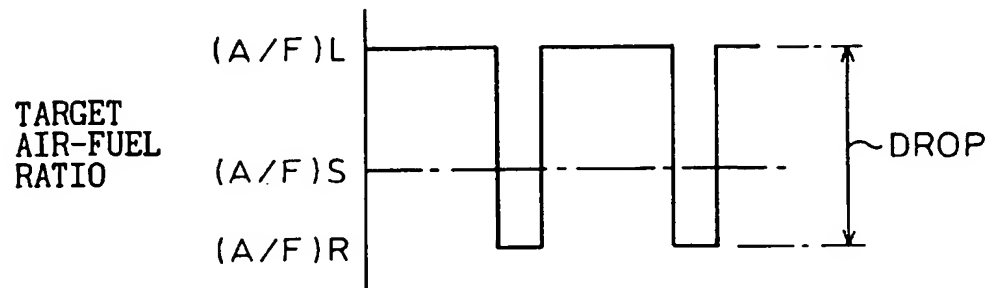
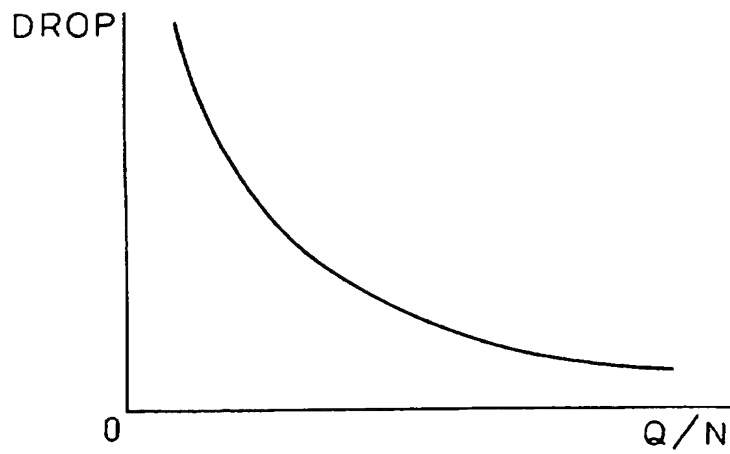


Fig .25B

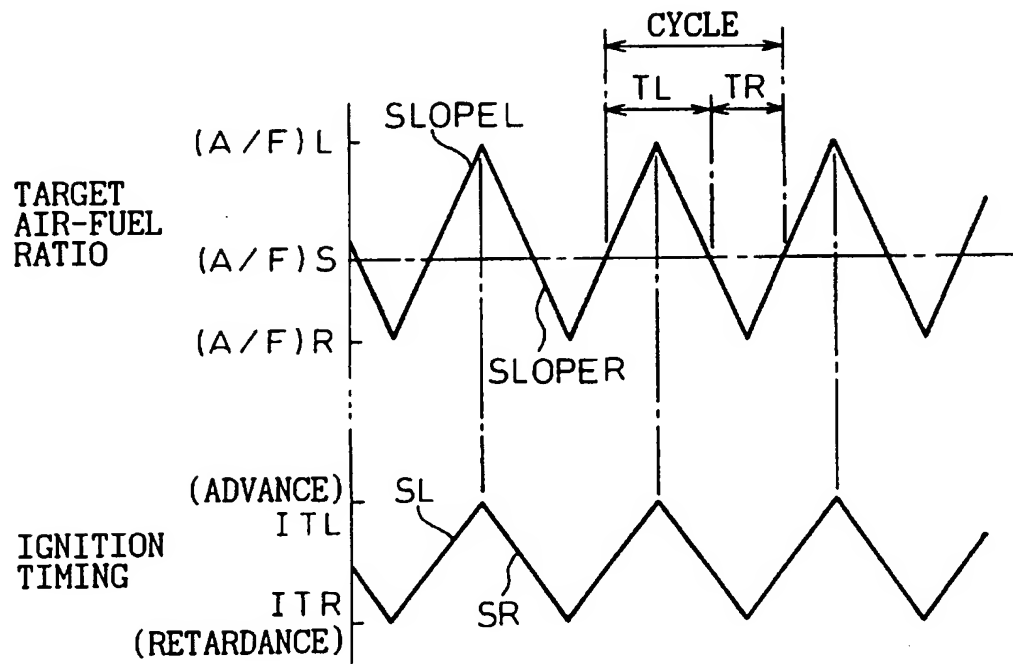


WO 97/17532

PCT/JP96/03205

20/44

Fig.26





WO 97/17532

PCT/JP96/03205

21/44

Fig.27

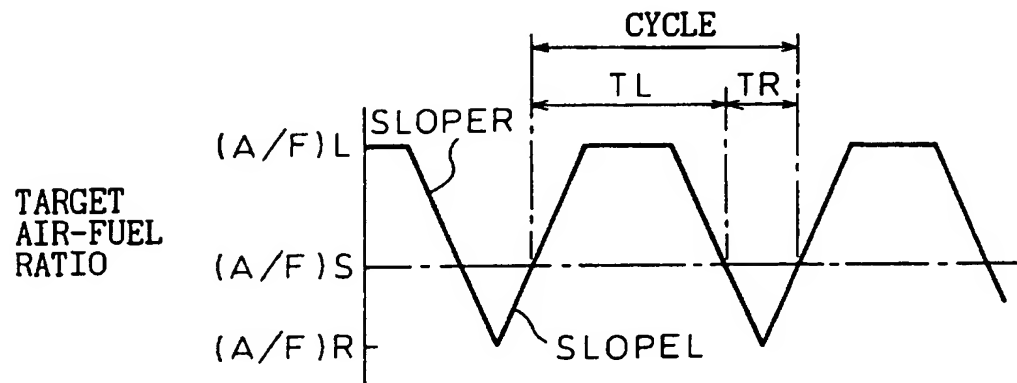
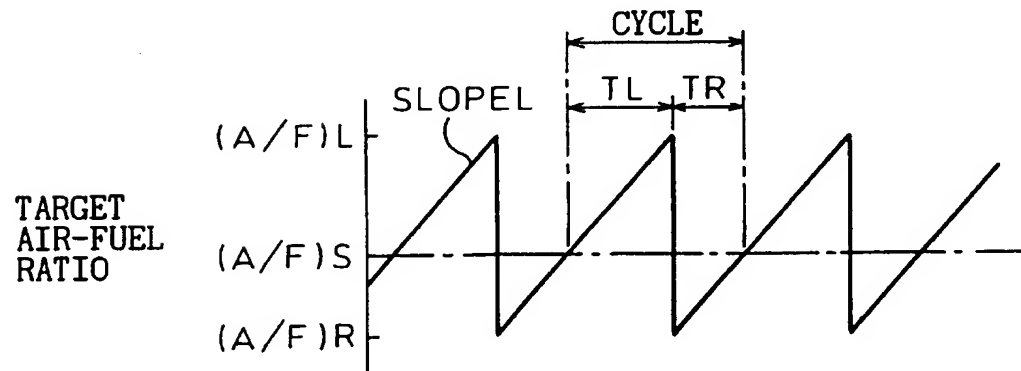


Fig.28



WO 97/17532

PCT/JP96/03205

22/44

Fig. 29

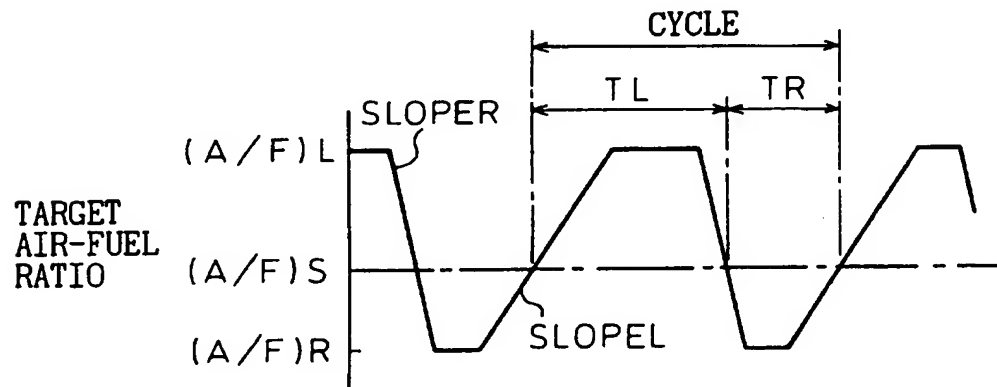
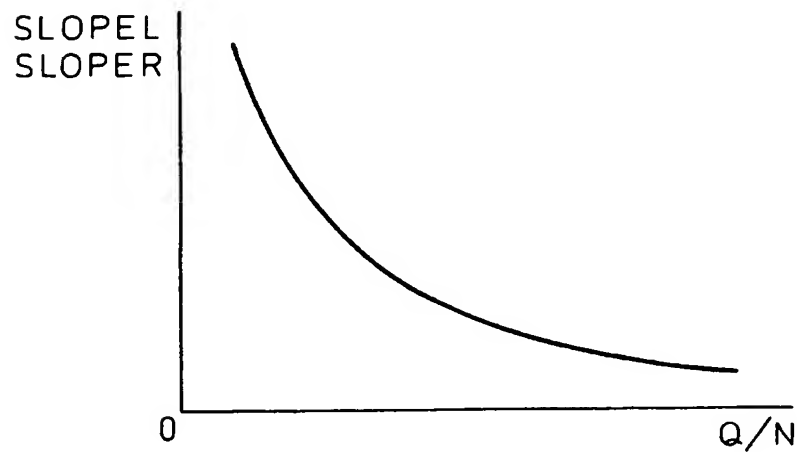
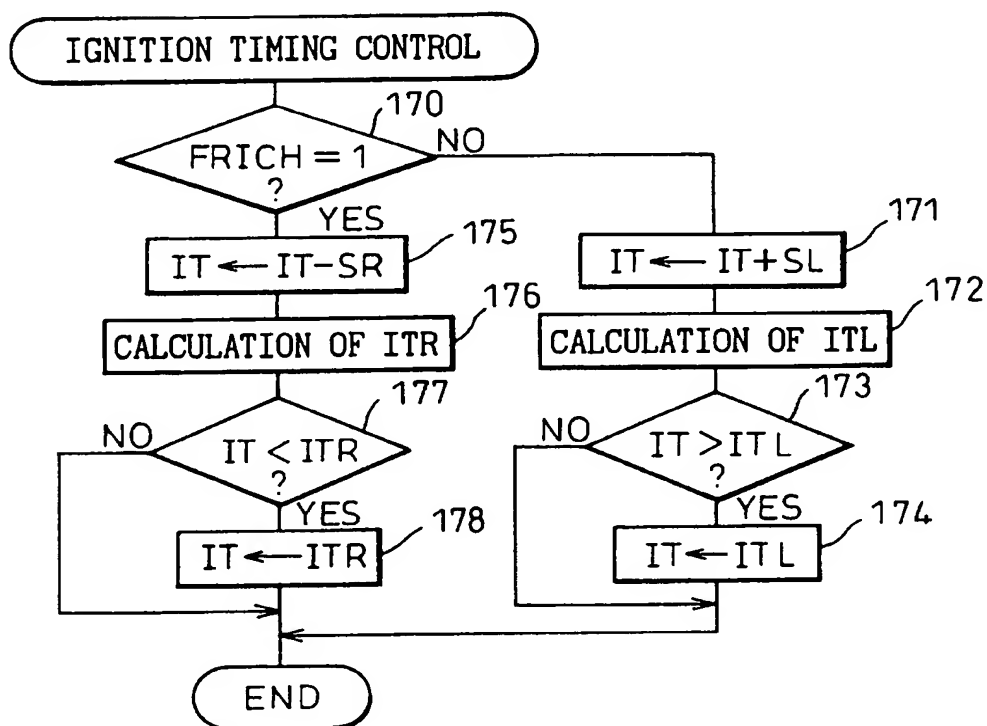


Fig. 30



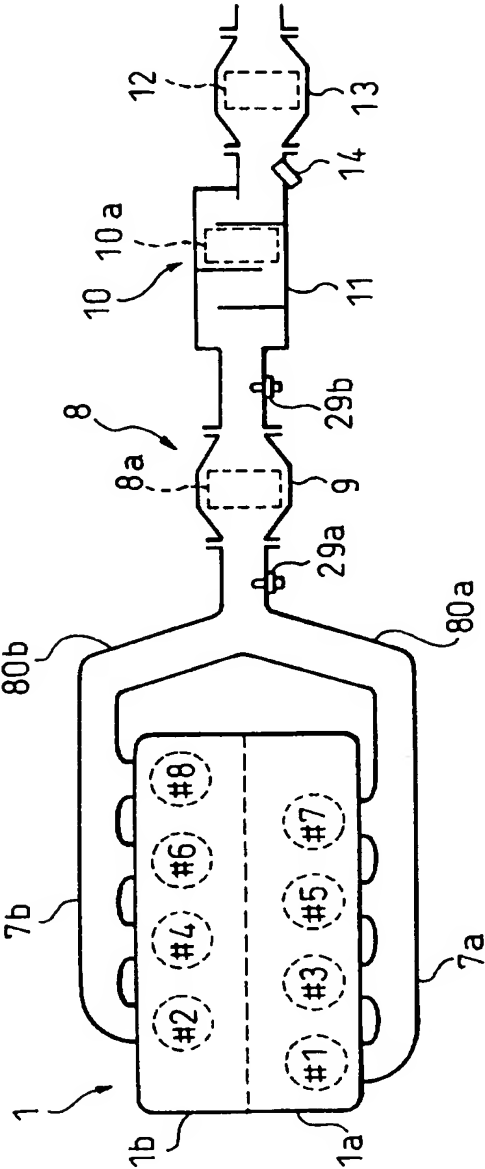
23/  
44

Fig. 31



24/44

Fig.32

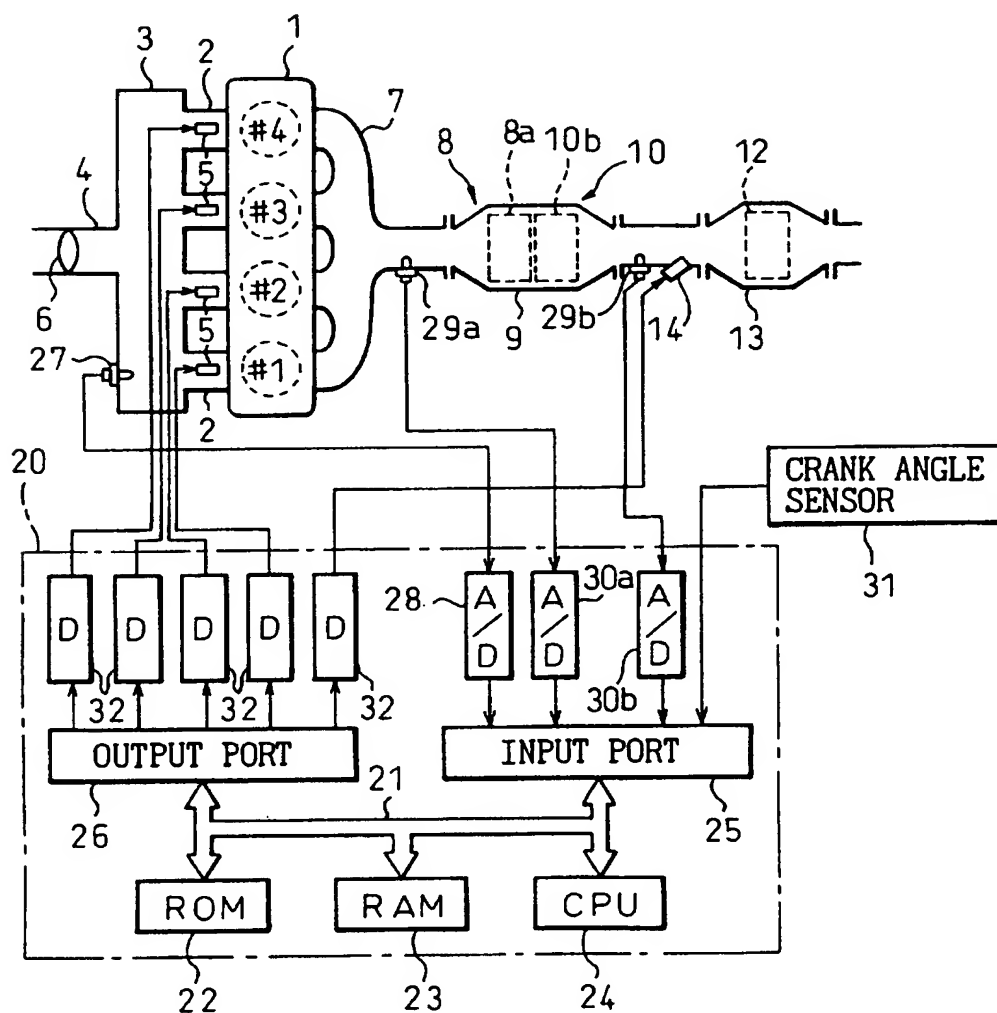


WO 97/17532

PCT/JP96/03205

25/44

Fig.33



WO 97/17532

PCT/JP96/03205

26/  
44

Fig.34A

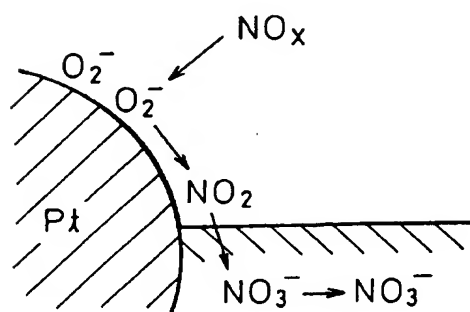
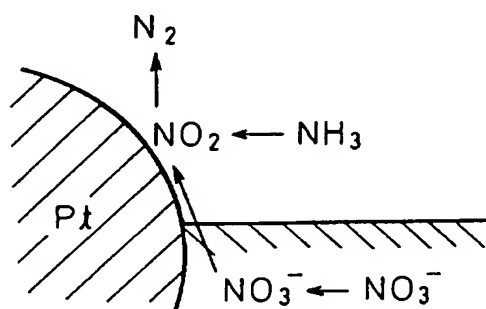


Fig.34B



27/44

Fig. 35A

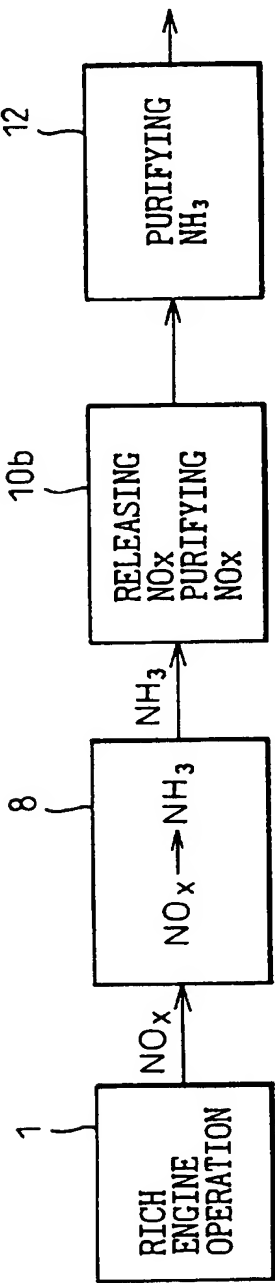
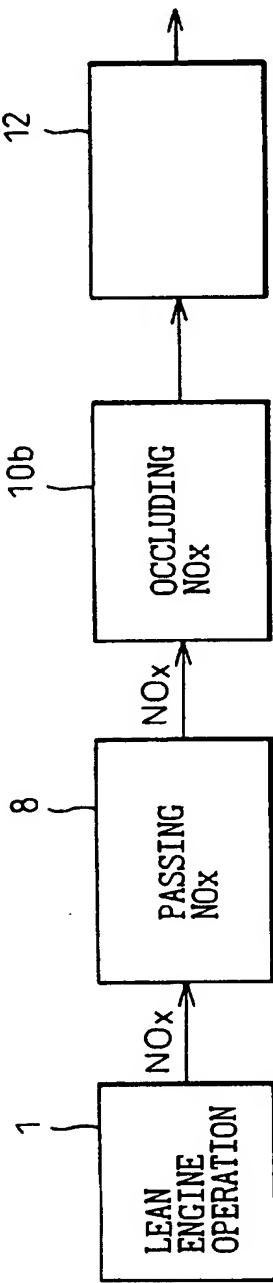


Fig. 35B



WO 97/17532

PCT/JP96/03205

28/  
44

Fig.36A

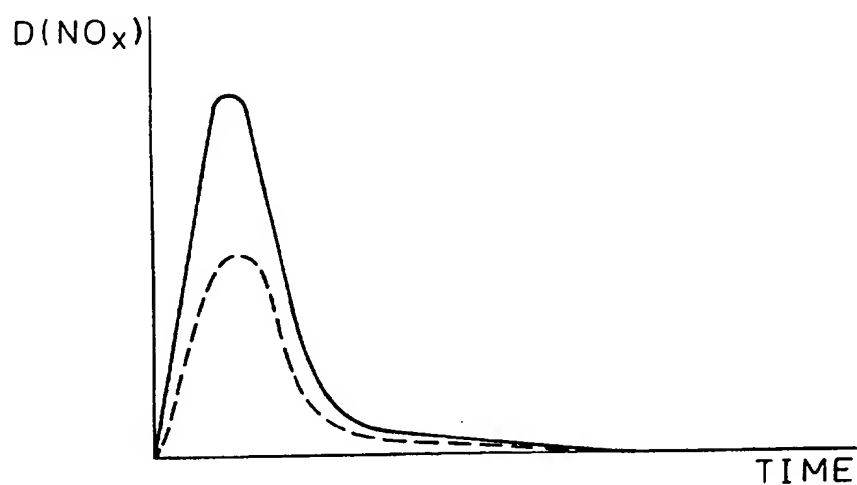
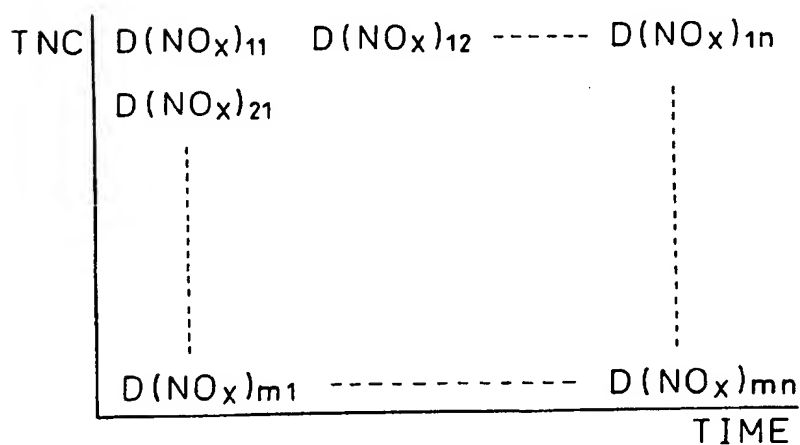


Fig.36B



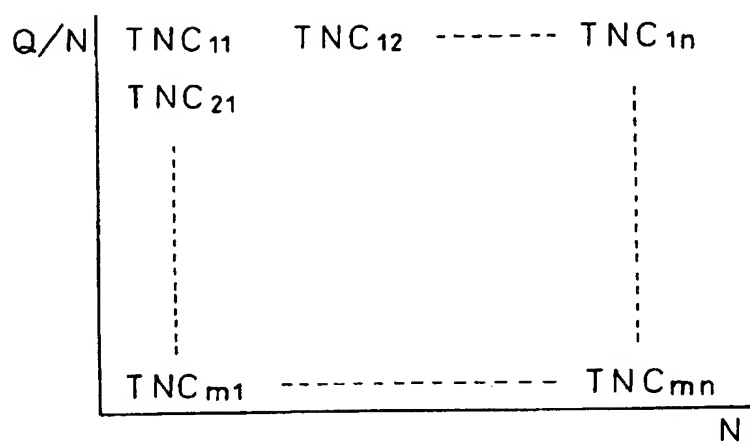


WO 97/17532

PCT/JP96/03205

29/  
44

Fig.37

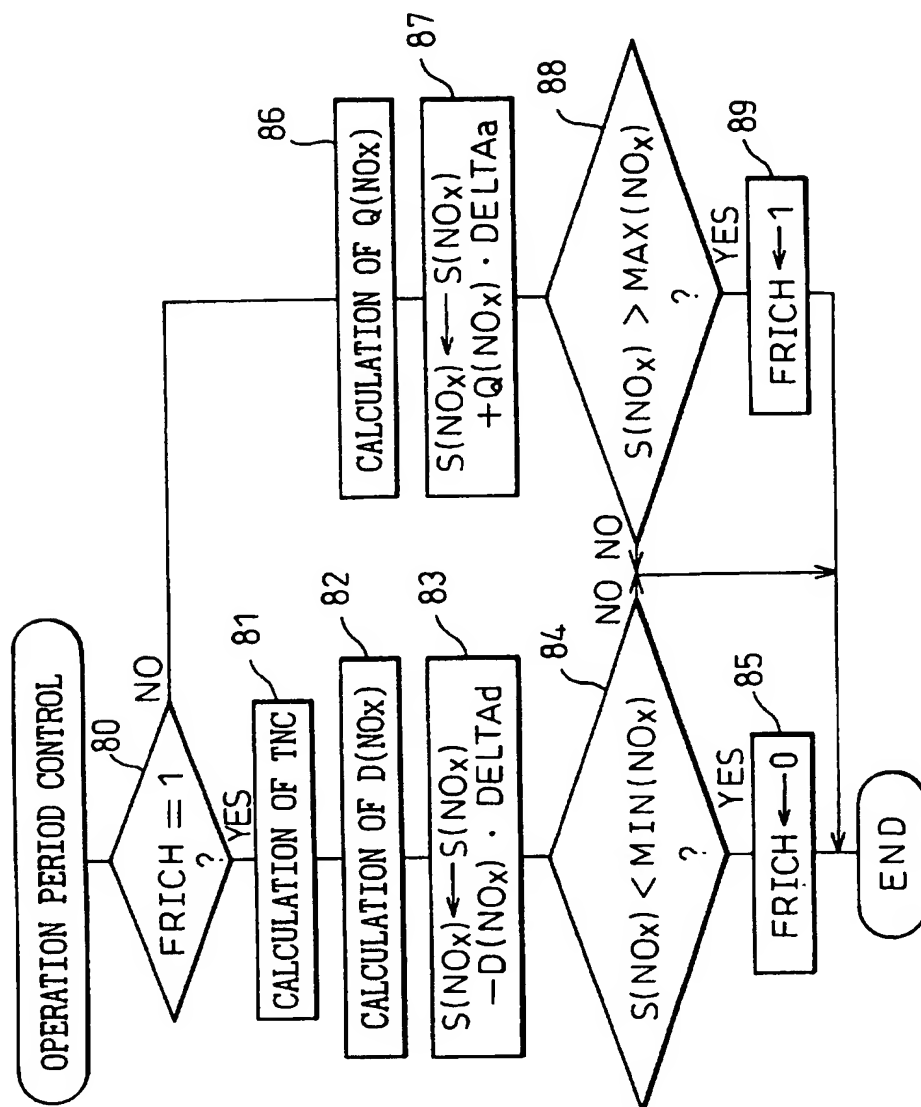


WO 97/17532

PCT/JP96/03205

30/44

Fig. 38A

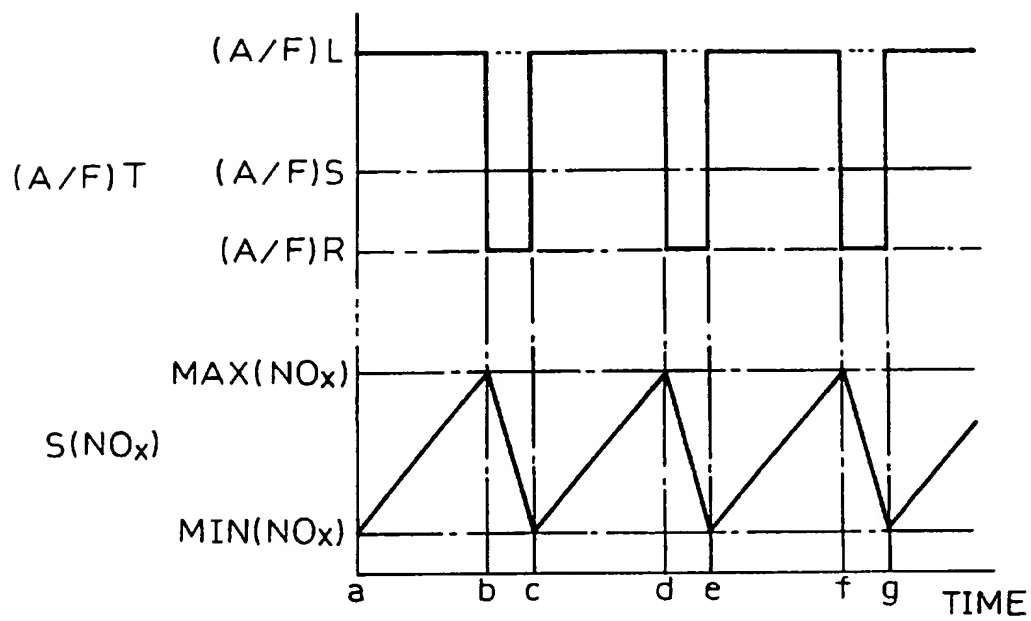


WO 97/17532

PCT/JP96/03205

31/44

Fig. 38B



32/44

Fig. 39

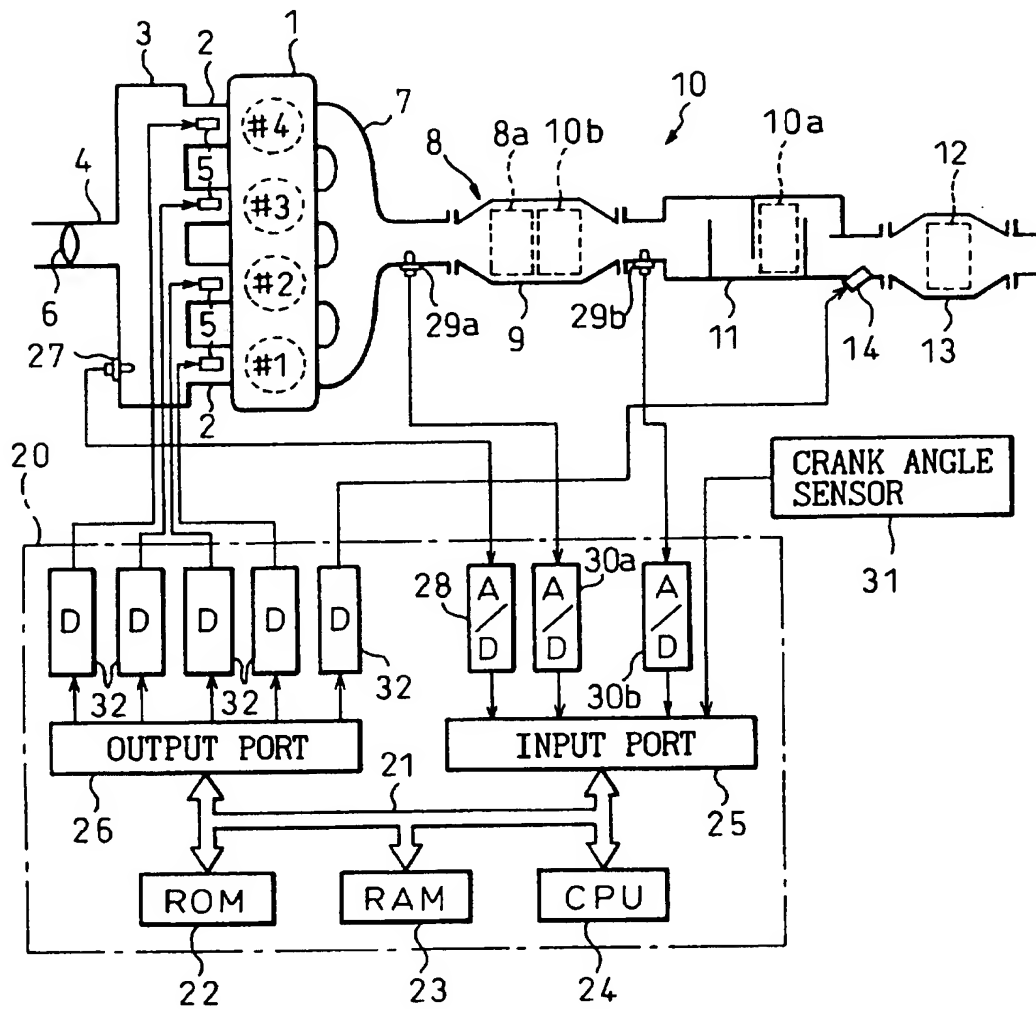


Fig. 40A

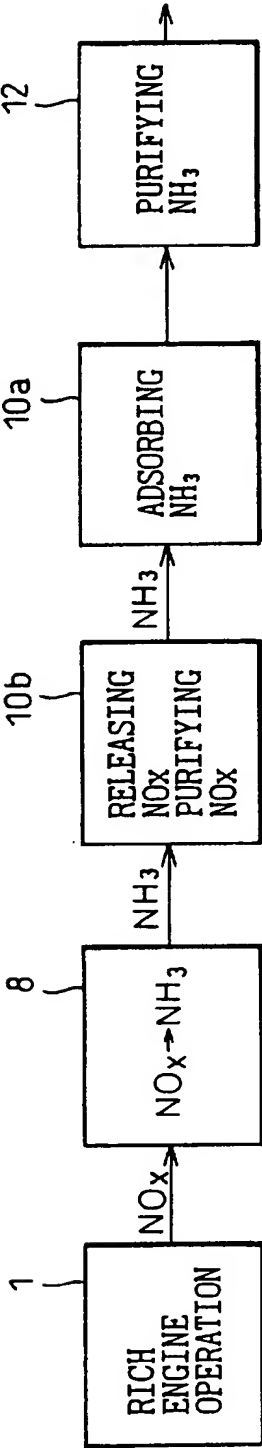
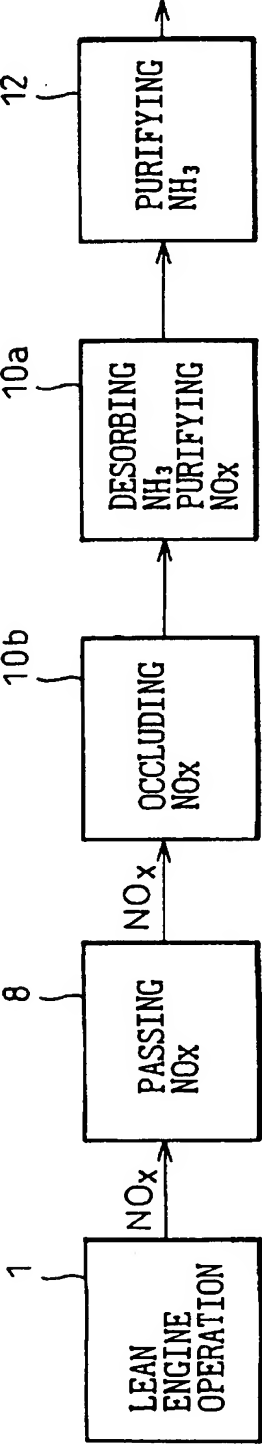


Fig. 40B



WO 97/17532

PCT/JP96/03205

34/44

Fig. 41A

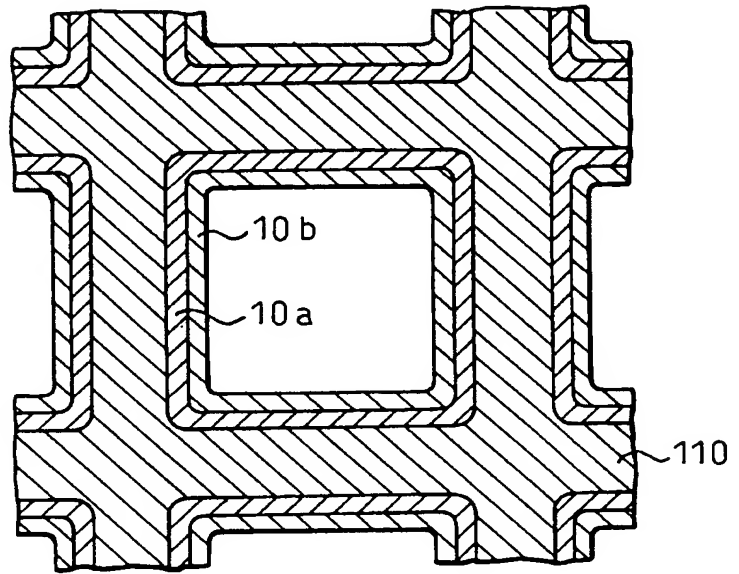
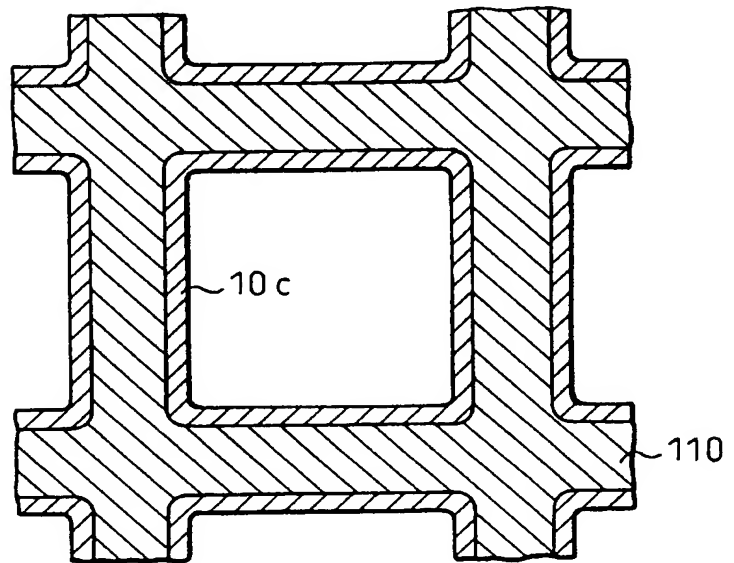
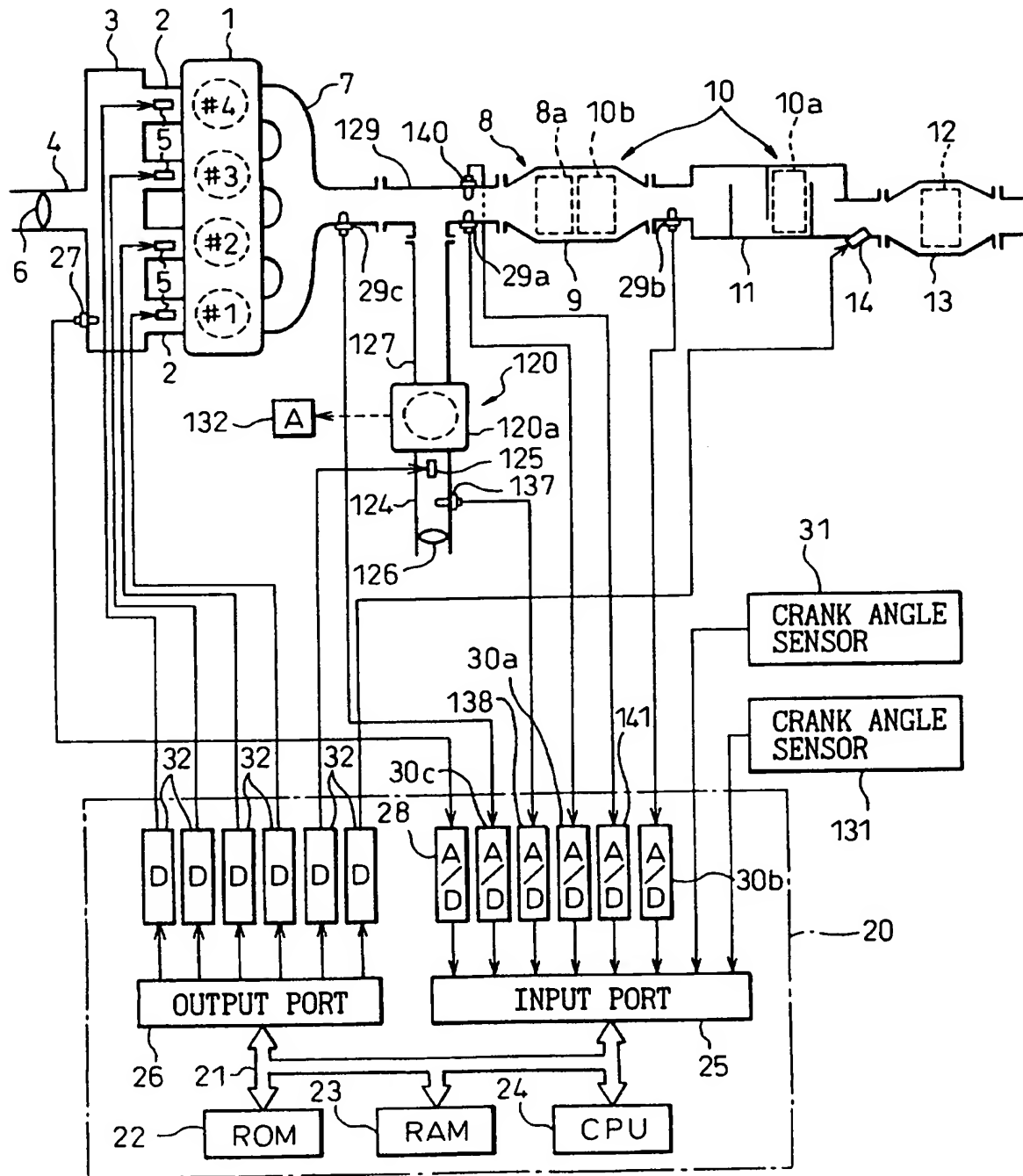


Fig. 41B



35/44

Fig. 42

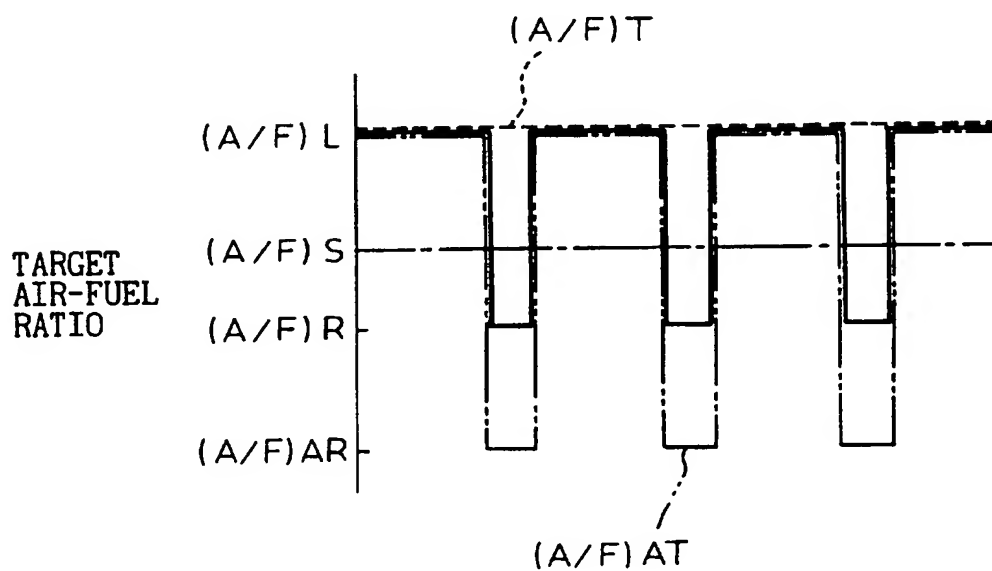


WO 97/17532

PCT/JP96/03205

36/  
44

Fig. 43A



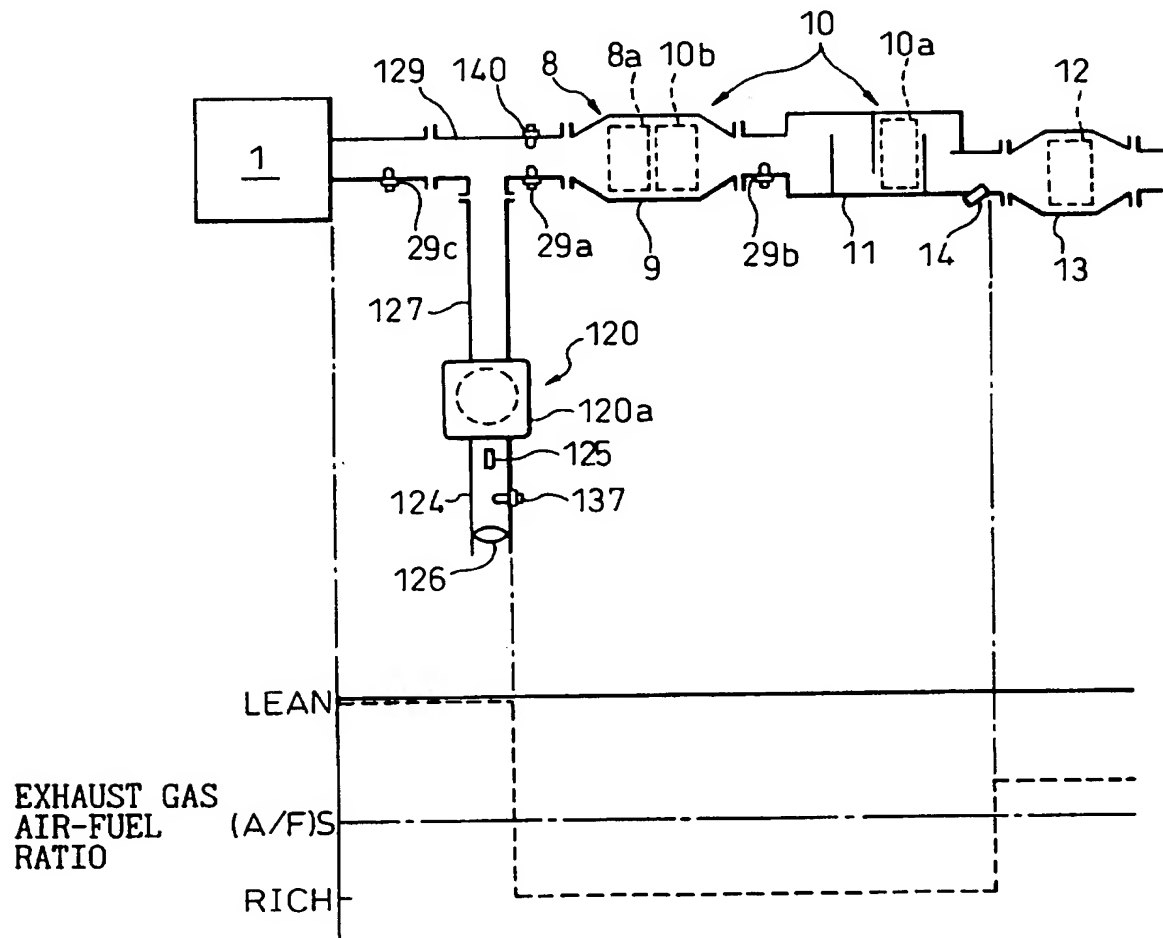


WO 97/17532

PCT/JP96/03205

37/44

Fig. 43B

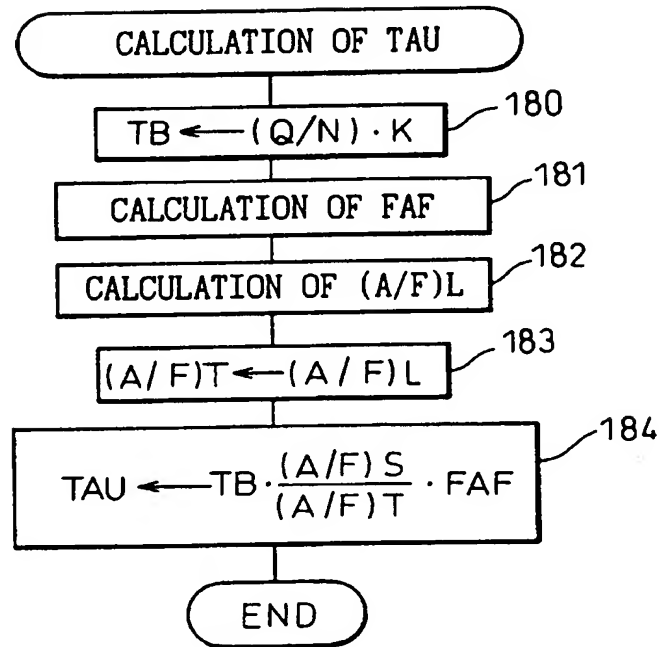


WO 97/17532

PCT/JP96/03205

38/44

Fig. 44



39/44

Fig. 45

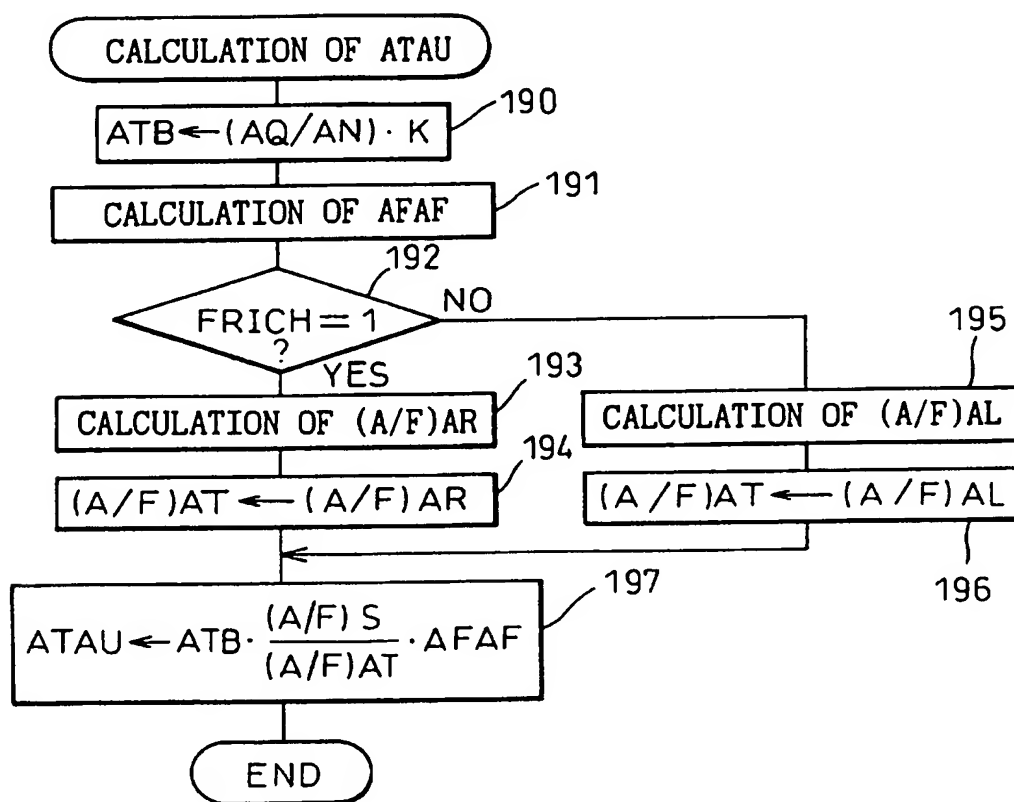
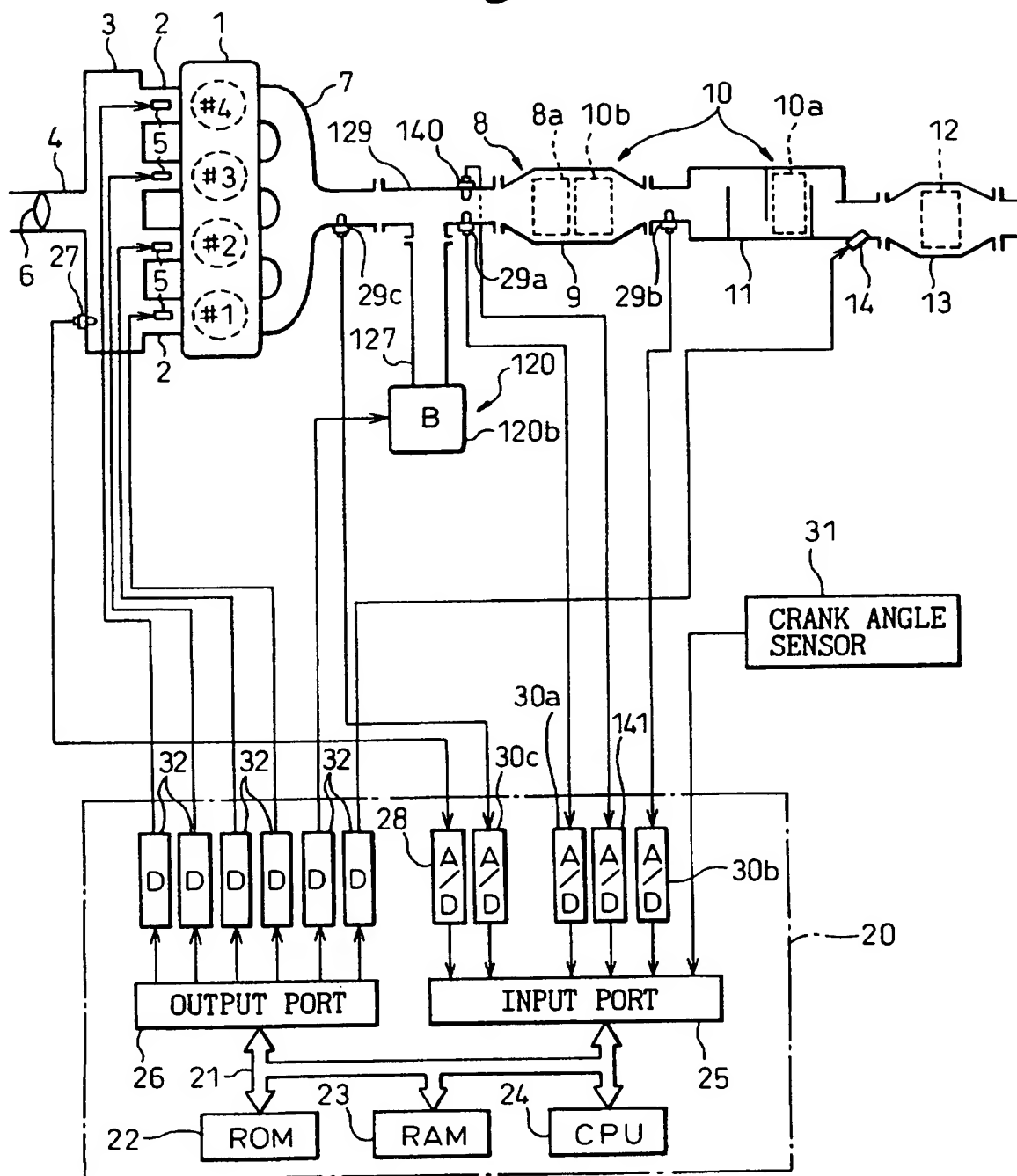


Fig. 46

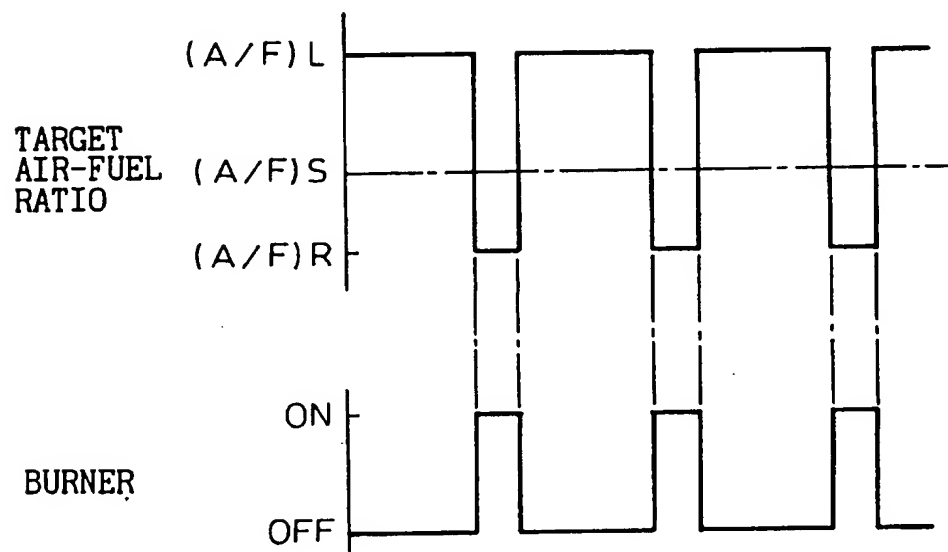


WO 97/17532

PCT/JP96/03205

41/  
44

Fig. 47

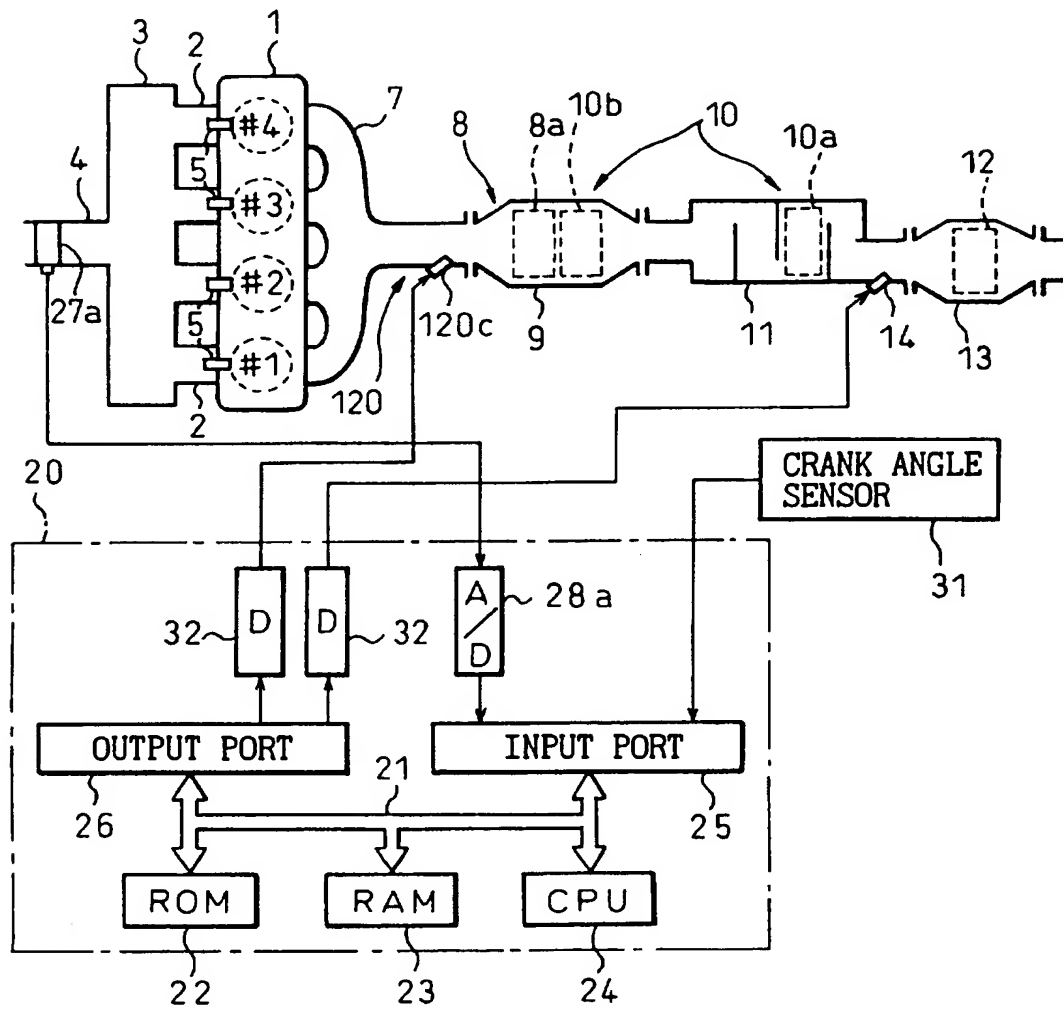


WO 97/17532

PCT/JP96/03205

42/44

Fig. 48

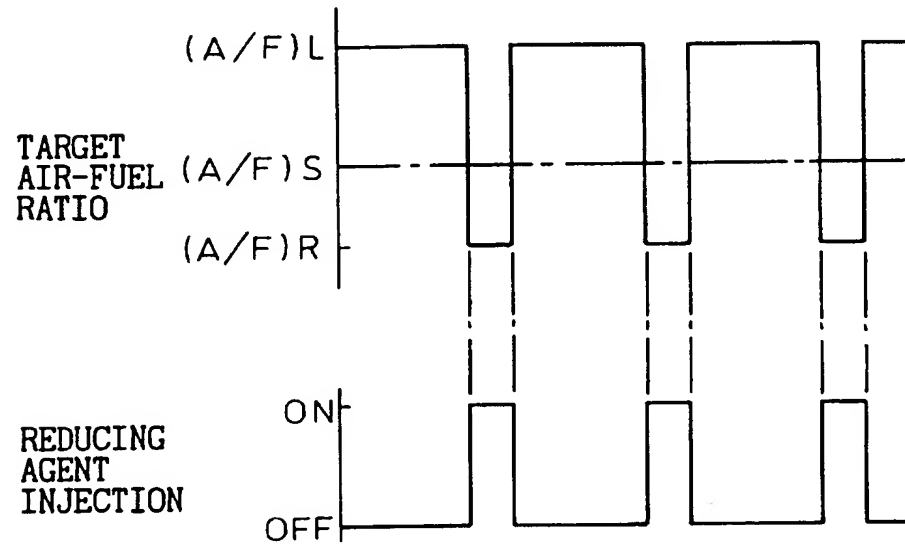


WO 97/17532

PCT/JP96/03205

43/  
44

Fig. 49



WO 97/17532

PCT/JP96/03205

44 / 44

# LIST OF REFERENCE NUMERALS

- 1 ... engine
- 5 ... fuel injector
- 7 ... exhaust manifold
- 8 ... NH<sub>3</sub> synthesizing catalyst
- 8a ... three way (TW) catalyst
- 10 ... exhaust gas purifying catalyst
- 10a ... NH<sub>3</sub> adsorbing and oxidizing (NH<sub>3</sub>-AO) catalyst
- 10b ... NO<sub>x</sub> occluding and reducing (NO<sub>x</sub>-OR) catalyst



## INTERNATIONAL SEARCH REPORT

International Application No

PCT/JP 96/03205

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 F01N3/08 F01N9/00 B01D53/94 F01N3/28 F01N3/20

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 F01N B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 017, no. 240 (M-1409), 14 May 1993 & JP 04 365920 A (TOYOTA CENTRAL RES & DEV LAB INC; OTHERS: 01), 17 December 1992, cited in the application  see abstract  ---	1-6,10, 17,22, 26,31, 34, 47-52, 63,68, 72,77
A	EP 0 510 498 A (CORNING INC) 28 October 1992  see column 7, line 29 - column 14, line 48; figures  ---  -/-	1,11,12, 14, 42-47, 57,58, 60,88-91

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Date of the actual completion of the international search

3 March 1997

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## INTERNATIONAL SEARCH REPORT

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A	PATENT ABSTRACTS OF JAPAN vol. 016, no. 036 (M-1205), 29 January 1992 & JP 03 244915 A (MITSUBISHI HEAVY IND LTD), 31 October 1991, see abstract	1, 11, 12, 14-16, 47, 57, 58, 60-62
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A	GB 1 453 456 A (TOYODA CHUO KENKYUSHO KK) 20 October 1976	

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Information on patent family members

International Application No

PCT/JP 96/03205

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EP 0701858 A	20-03-96	JP 8135437 A	28-05-96
US 3825654 A	23-07-74	NONE	
GB 1453456 A	20-10-76	JP 1033368 C JP 49071313 A JP 55018539 B	20-02-81 10-07-74 20-05-80